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TEST BAN ISSUES

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TEST BAN ISSUES

THURSDAY, OCTOBER 6, 1988

U.S. SENATE,
COMMITTEE ON FOREIGN RELATIONS,
Washington, DC.

The committee met at 10:05 a.m., in room SD–419, Dirksen Senate Office Building, Hon. Claiborne Pell (chairman of the committee) presiding.

Present: Senators Pell, Adams, and Pressler.

OPENING STATEMENT OF HON. CLAIBORNE PELL, A U.S. SENATOR FROM RHODE ISLAND

The CHAIRMAN. The Committee on Foreign Relations will come to order.

I am very glad to welcome our witnesses this morning. Ambassador Robinson is just back from intensive negotiations with the Soviets in Geneva on verification protocols to the 1974 Threshold Test Ban Treaty, the 1976 Peaceful Nuclear Explosions Treaty. He will give us the progress report. I am delighted to welcome him and our subsequent panel.

I wish Ambassador Robinson and our President every success in concluding the negotiations and reaching workable agreements before the present administration leaves office. If he is successful, I as chairman of this committee will give top priority to consideration of the protocols next year. I hope we will be able to move expeditiously thereafter to consideration by the Senate of the two treaties and the new protocols.

When the Threshold Test Ban and the Peaceful Nuclear Explosion Treaties are ratified, I believe we should push hard for early agreement to reduce the permitted yields and the numbers of tests. I believe we should be able to marshal the necessary support to reduce the ceiling and safety to the present 150 kilotons to maybe as low as 10 kilotons, a level that could be monitored with high confidence. We could later move down to 1 or 2 kilotons. A complete ban would be possible only when there is general acceptance that our monitoring and restrictions are good enough to ensure that no cheating is possible that could outweigh the advantages of a ban.

I hope the new administration will be convinced of the merits of negotiating a new treaty that moves us steadily toward the early achievement of a complete ban. And I hope that the new administration will understand the vital importance of moving forth so that we can curb the development of new weapons, decrease our re-

liance upon nuclear weapons and show other potential nuclear weapon states that we are serious about halting nuclear weapons tests.

I am very glad at this point to hear from Ambassador Robinson. I wish him well.

STATEMENT OF HON. PAUL C. ROBINSON, U.S. NEGOTIATOR FOR THE NUCLEAR TESTING TALKS

Ambassador ROBINSON. Senator Pell, thank you very much for the opportunity to appear with you this morning.

I do have a statement prepared for the record, and I would like to briefly summarize some of the points in that.

The CHAIRMAN. It will be inserted in the record in full.

Ambassador ROBINSON. We are presently in the sixth week of the third round of these talks. Round I, held last November, was an initial session to organize the talks and prepare for some familiarization visits of experts to the two test sites. Those visits were then conducted in January of 1988.

Round II of our talks began on February 15 and, indeed, was a marathon session extending until June 28. In that session we not only negotiated the Joint Verification Experiment Agreement and began work and preparations by each side for the conduct of that experiment, but we also began initial work in parallel in development of new protocols to secure effective verification for the 1974 treaty on limitation of underground nuclear tests, the Threshold Test Ban Treaty, and the 1976 treaty on underground nuclear explosions for peaceful purposes, popularly known as the Peaceful Nuclear Explosions Treaty, or PNET.

These treaties, as you know, were negotiated more than a dozen years ago and have never been ratified by the sides. Our goal is to ratify those treaties.

Both sides agreed early that in those negotiations we would not make changes to the treaty language themselves, but to negotiate improved verification procedures which would result in a level of effective verification which would allow the treaties to be ratified.

At the end of Round II, we had completed a joint draft text of the PNET protocol and each side had tabled separate drafts for the TTBT protocol.

As you know, the Joint Verification Experiment, which we agreed to conduct with the Soviet Union, was an idea on the Soviet side. We now say it was a very good idea to conduct these experiments ahead of trying to finalize language on the verification procedures. The condition was that the tests be conducted and the results analyzed before they would be willing to finalize the verification parts of these protocols. Now that the treaties have been successfully conducted, we are now engaged in those talks. The data analysis is nearly complete, and we are looking at finalizing both of the treaties in the near future.

The JVE had two explosions. The one in the United States took place on August 17 at the Nevada test site. A similar explosion took place in the Soviet Union on September 14 at the Semipalatinsk test site.

I find it remarkable that as we negotiated those agreements, the schedule that we proposed turned out to be exactly met by both sides. The full set of verification methods was evaluated in the experiments, and I believe both sides are quite pleased with the participation and the outcome of those experiments.

The United States and the Soviet equipment performed quite well in recording the data related to yields at both sites. And we have exchanged the data recordings and some preliminary analyses, and these show only small differences in the results for the hydrodynamic measurement methods. I am pleased to note that the uncertainties associated with these hydrodynamic measurements are less than the 30-percent value which we have always assigned as accuracy for the CORRTEX hydrodynamic method, the U.S. method.

The experience of the JVE I think has been really a valuable one for both sides—I can even use the word "historic"—in arms control that we were able to try ahead of finalizing language on an experimental basis the techniques to be applied. It made the rate at which we were able to make progress far faster than it could have gone otherwise if you were trying to make sure all the language must stand for all time.

There were, indeed, problems which arose, as I think there have been in all agreements. We were able to solve them in each case in a businesslike manner, and I believe the experience gained from both that problem solving and the execution of the Joint Verification Experiments have put us in a very solid position to finalize the protocols with the verification techniques incorporated.

The schedule that we have taken for a goal is to complete these protocols during this administration. As you know, we have been devoted to a very heavy schedule. We will remain in continuous session in Geneva. Indeed, there is a meeting going on at the present time this afternoon in Geneva.

Once we secure effective verification in these treaties and their protocols and can ratify those treaties, the United States will immediately propose negotiations on ways to implement the step-by-step parallel program in association with the program to reduce and ultimately eliminate all nuclear weapons to limit and ultimately end nuclear testing.

Thank you, sir, for your attention. I would be happy to answer any questions you may have.

[The prepared statement of Ambassador Robinson appears in the appendix.]

The CHAIRMAN. Thank you very much, indeed, Dr. Robinson.

First, speaking more as a layman, I am correct in saying I believe that the CORRTEX was a system that we liked where you dropped the parallel wire down the hole, down a separate hole. The Soviet system before was one based upon the explosive force going out through the rocks. Is that roughly correct?

Ambassador ROBINSON. In the original treaty, the 1974 and 1976 treaties, for the weapons treaty we had depended upon a seismic method operating by national technical means, instruments placed only in the United States. Looking at Soviet tests, similarly Soviet tests—Soviet instruments in their national boundaries looking towards our tests.

For the Peaceful Nuclear Explosions Treaty protocol, it included hydrodynamic measurements. At that it was an early generation of our CORRTEX system. The Soviets had similarly developed an early generation hydrodynamic methodology. That that particular treaty was never ratified meant a CORRTEX hydrodynamic measurement never took place until this one in the JVE.

So, the methods have been around for a long time and were understood by both sides. We are now moving forward to try and implement them both.

The CHAIRMAN. And am I correct in saying that as a result of the JVE, both sides accept CORRTEX as being the basis for watching in the future?

Ambassador ROBINSON. It is too soon for me to make that statement on an absolute basis. When we have completed these protocols, only then will we have the answer.

I believe I can state for you at this time that both sides are quite pleased with the results of the experiments, and certainly the data that we have exchanged shows close accuracy between the two methods.

The CHAIRMAN. I appreciated your statement tremendously, and I was most heartened and struck by your last sentence of your prepared statement. "This done, we will immediately propose negotiations on ways to implement a step-by-step parallel program—in association with a program to reduce and ultimately eliminate all nuclear weapons—of limiting and ultimately ending nuclear testing."

I am delighted because I concur, but I just want to be sure I heard correctly. Would this be an administration position or is this more your own personal position?

Ambassador ROBINSON. It is the administration position and the agreement that President Reagan made with General Secretary Gorbachev in opening our negotiations. Indeed, the U.S. position, the administration position, has not changed. I read publicity within the last several weeks that suggested in some people's minds that there might have been a change. Sir, there has not been.

The CHAIRMAN. So, the ultimate goal of the administration is the elimination of all nuclear weapons.

Ambassador ROBINSON. I believe we all would like for a world in which we did not have to rely on nuclear weapons to maintain international stability. In that sense, when it can be achieved, we would no longer have a requirement for nuclear testing.

We do not consider nuclear testing as an end in itself. Similarly, arms control is not an end in itself. They are both tools by which we try and secure world stability and, most importantly, the national security of the United States.

The CHAIRMAN. Basically then you think both sides can reach some sort of agreement in the protocols this year, calendar year 1988.

Ambassador ROBINSON. That is our goal, and both sides are working very, very hard to achieve that. Yes, sir.

The CHAIRMAN. What would you say were the principal remaining obstacles?

Ambassador ROBINSON. First of all, in an open session, Senator Pell, it is hard for me to break the confidentiality of our agreements.

The CHAIRMAN. I understand.

Ambassador ROBINSON. It would not be helpful for me to telegraph our positions early nor to criticize the Soviet positions in public.

We do have the principal verification methods associated with the Threshold Test Ban, those which were to be explored and evaluated in that Joint Verification Experiments. I think we are on schedule following those tests for the taking up of those matters and resolving them.

The CHAIRMAN. I think your point is well taken.

In a report to Congress on September 8, the President indicated that the United States may need to expand its nuclear testing program even if Moscow and Washington agree to cut their nuclear arsenals. I was wondering if you would comment on that thought.

Ambassador ROBINSON. I'm not sure I know the exact quote. In our report to Congress——

The CHAIRMAN. In the report to Congress on September 8, I am informed the President indicated that we may need to expand our nuclear testing program even if Moscow and Washington agree to cut their nuclear arsenals.

Ambassador ROBINSON. We have said that the level can be zero nuclear tests when we no longer need to depend upon nuclear weapons for our security. Today we do testing at a certain level. The Soviets test at a similar and slightly higher level.

I think the important question is as we achieve arms control reductions in the START process, the exact nature of that agreement will affect the test program. Particularly, it is not the total number of weapons that are built; it more importantly is the number of systems which are available. If you can design and build a weapon and test to prove its reliability at intermittent periods, you can build any number you would like without changing the basic methodology for development of our tests.

It is going to depend upon what the formula is in that START agreement. How many systems will have to be maintained through testing by both sides? I don't think we know an exact number yet, and it would be premature to state what the exact consequence will be until we see what that START agreement looks like.

The CHAIRMAN. As you know, our committee reported out these two treaties I think in January or February of 1987. And then they have stayed on the calendar ever since. I gather that you think that these could be taken up again in the new Congress and hopefully passed as a result of these negotiations.

Ambassador ROBINSON. That is my highest goal, yes, sir.

The CHAIRMAN. What would be your reaction it is unlikely to the thought that they might come up for recommendation for ratification in the last week of the session?

Ambassador ROBINSON. We intend to work as hard as we can during this year to try and complete it. I think I would have a better answer for you probably in a month after we have had the session of looking at those verification sections for the Threshold Test Ban which resulted from the Joint Verification Experiment. If

those go well, I think we can keep a more accelerated schedule. If there are more problems to resolve, it will take longer.

The CHAIRMAN. Where are the negotiations taking place?

Ambassador ROBINSON. All the negotiations are focused on Geneva from here on. We are back to Geneva, and that's the only center for the discussions.

The CHAIRMAN. And when do you expect the negotiations to wrap up? Thanksgiving or Christmas?

Ambassador ROBINSON. Sometime between Thanksgiving and Christmas, yes.

The CHAIRMAN. Thank you very much, indeed. I congratulate you on what you are doing and support you to the hilt.

Ambassador ROBINSON. Senator, we appreciate your support. Thank you.

The CHAIRMAN. We now come to our panel, if they would come forward. Dr. Peter Sharfman, Program Manager, International Security and Commerce, Office of Technology Assessment, OTA; accompanied by Dr. van der Vink. Then we have Professor David Hafemeister, Professor of Physics, California Polytechnic State University; and Dr. Milo Nordyke, Principal Scientist of the Treaty Verification Program from the Lawrence Livermore Laboratory.

Mr. Sharfman, would you lead off?

STATEMENT OF DR. PETER SHARFMAN, PROGRAM MANAGER, INTERNATIONAL SECURITY AND COMMERCE, OFFICE OF TECHNOLOGY ASSESSMENT

Dr. SHARFMAN. Thank you, Mr. Chairman. I have a brief prepared statement, but with your permission, I will submit that for the record and summarize my remarks.

The CHAIRMAN. Certainly.

Dr. SHARFMAN. I am Dr. Peter Sharfman, the Program Manager for International Security and Commerce at the Congressional Office of Technology Assessment. With me is Dr. Gregory van der Vink who directed our assessment of seismic verification of nuclear testing treaties.

This study took a year and a half to complete primarily because of an exhaustive process of review and revision designed to ensure that we really did capture a consensus of the technical community. We had a 19-member advisory panel with representatives from the national laboratories, the intelligence community, the arms control community and the geophysical research community. And in addition, we had 4 days of technical workshops bringing in a total of something over 50 scientists. All of these people reviewed successive drafts of our report, and we delayed issuing the report until we had a draft that all of our reviewers agreed was as close to being correct as one could reasonably expect.

I should make it clear at the outset that the purpose of limitations of underground nuclear testing is to limit the development and refinement of nuclear weapons and other military systems. Therefore, the issue of what limitations are desirable cannot be resolved without an assessment of the military significance of various kinds of limits. However, OTA has not carried out such an analysis. We can, therefore, speak only to the question of what can be

verified or what could be verified. We can say nothing about what the United States might want to verify.

I would like to make a couple of general statements about verification as well. Realistically verification can never be perfect or absolute. It necessarily involves some degree of uncertainty which is usually described in probabilistic terms. Consequently, the question of whether a treaty is verifiable can never be answered in any absolute or technical sense because it requires decisions about what constitutes an acceptable level of uncertainty. The degree of verification needed is based on one's perception of the benefits of the treaty compared with one's perception of the disadvantages and the likelihood of violation.

To explain this process, our report uses an analogy of someone deciding whether they can safely cross a frozen river. If the water is deep and there is nothing worth having on the other side, then the ice does not have to be very thin to discourage someone from crossing it. On the other hand, if the water is shallow and there is something of great value on the other side, then the ice must be very thin, indeed, to dissuade a party from trying to cross. Deciding whether a monitoring system provides adequate verification is like deciding whether the ice is so thin that it deters crossing.

What we are able to present is an assessment of the thinness of the ice. Whether ice of a given degree of thinness—that is, a given probability that we would detect a violation—constitutes adequate verification is a question that must be answered on political grounds by the policymaking community.

I would now like to ask Dr. van der Vink to present our specific findings.

[The prepared statement of Dr. Sharfman appears in the appendix.]

The CHAIRMAN. Thank you very much.

STATEMENT OF DR. GREGORY E. VAN DER VINK, PROJECT DIRECTOR, INTERNATIONAL SECURITY AND COMMERCE, OFFICE OF TECHNOLOGY ASSESSMENT

Dr. VAN DER VINK. Senator Pell, it is a pleasure to appear before the committee. I am Dr. Gregory van der Vink, and I was the project director of OTA's study on seismic verification. With your permission I would like to submit my written statement for the record.

The CHAIRMAN. Without objection.

Dr. VAN DER VINK. And then I will just summarize two questions that were addressed within our study: namely, has the Soviet Union violated the 1974 Threshold Test Ban Treaty; and down to what size explosion can we seismically monitor nuclear testing within the Soviet Union? First, let me address the issue of Soviet compliance.

The 1974 Threshold Test Ban Treaty restricts the testing of underground nuclear explosions to yields no greater than 150 kilotons. Questions concerning Soviet compliance have arisen with findings by the Reagan administration that a number of Soviet tests constitute a likely violation.

In examining compliance with the 150 kiloton limit, seismic evidence is currently considered the most reliable basis for estimating the yields of Soviet underground nuclear explosions. Consequently, it is the interpretation of the seismic data that controls the debate on the compliance question.

I need to emphasize that yield estimation is a statistical measurement. Therefore, the question of compliance should not be addressed by looking at individual tests, but rather by examining the entire pattern of Soviet testing.

A rather clear illustration of the danger of looking at an individual test occurred during the recent United States-Soviet Joint Verification Experiments. As part of these experiments, several dozen Soviet scientists were invited to the Nevada test site to witness the use of the on-site CORRTEX method.

As reported by the Washington Post, the CORRTEX system measured the yield of the test explosion as being around 155 to 160 kilotons, an apparent violation of the 150 kiloton limit. The Post article also included statements from U.S. officials claiming that the test was not a violation and that the true yield was approximately 145 kilotons. In fact, Ambassador Robinson was quoted in that article as saying that the test was clearly below the treaty limit.

The point I wish to make here is that the CORRTEX measurements above 150 kilotons for the U.S. test does not mean that the United States violated the treaty, nor does it mean that CORRTEX is an inadequate method of yield estimation. In fact, CORRTEX performed well within its advertised capability. But it is, in fact, the nature of this type of measurement that if testing occurs up to the yield limit and the measurements have uncertainty, some tests will appear as being slightly above the limit.

Obviously, what would be most useful to the Congress would be a definitive answer as to whether the Soviets have cheated. Yet, every method of yield estimation—and I emphasize every method—has some uncertainty associated with it. This, however, does not mean that the treaty is unenforceable.

I would like to, sir, propose the somewhat inadequate analogy of the monitoring of the automobile speed limit. The police use radar measurements to catch drivers that exceed 55 miles per hour. Under the 150-kiloton limit, an observed yield of 160 kilotons (as was produced in the recent Joint Verification Experiments), is like a radar reading of 58.7-miles per hour under a 55-mile per hour limit. The police generally do not give tickets when their radar shows a speed of 58.7-miles per hour because most speedometers are not that accurate or well calibrated and because curves and other factors in the measurement lead to small uncertainties in the radar estimate. Similarly, a 160-kiloton measurement should not be regarded as a legal lack of compliance because such a number can well arise from uncertainties in the measurement technique.

At radar measurements above 65-miles per hour, the police do not question that the 55-mile per hour limit has been exceeded, and the speeder gets a ticket. At this level of accuracy, it would take a calculated yield of about 180 to 190 kilotons to conclude that a violation had likely taken place.

I have to emphasize here that this argument does not necessarily mean that the Soviets could take advantage of this uncertainty and therefore test at 180 to 190 kilotons. They would have to worry that the uncertainty might work against them; in other words, they might test at 180 or 190 and the uncertainty in the measurement might result in their test appearing as 200 which would, therefore, be a clear violation.

However, the point is worth noting that the calculated yield for declaring a treaty violation will be higher than the limit of the treaty. Consequently one or two small breaches of the treaty could occur within the expected uncertainty of the measurements. A country intent on cheating might try and take advantage of this by risking one or two tests above the limit, just as a driver might risk driving slightly above the 55-mile per hour speed limit past a police car on the assumption that neither his speedometer nor the radar measurement will be high, and so he can take advantage of this margin of error.

Even if discovered—and this is where my analogy with the police breaks down (especially with the Maryland State troopers that I have had experience with)—a rare violation slightly above the threshold could be explained away as an accidental violation due to an incorrect prediction of the precise yield of the nuclear explosion. Such accidental violations are accepted by the treaty's so-called "whoops" consideration that accounts for slight unintendedended breaches, of the limit.

When negotiating a treaty, the thresholds should be chosen very carefully to ensure that any small violations (whether they are apparent or real), do not fall in a range that is considered to be militarily significant.

Given all this, we can still make judgments about compliance. Since the signing of the Threshold Test Ban Treaty in 1974, the Soviet Union has conducted over 200 underground nuclear explosions. The seismic data indicates that about 10 of these tests may have had estimated yields above the 150-kiloton limit. However, when the same method of yield estimation is applied to U.S. tests, approximately the same number of U.S. tests also appear to be above the 150-kiloton threshold limit. These results are expected, as I mentioned before, if both sides are testing up to the limit.

All of the estimates of Soviet tests are within the 90 percent confidence limit that one would expect if the yields were 150 kilotons or less. Statistical studies of the distribution of estimated yields of explosions at the Soviet test site conclude that the Soviets are observing a limit. The best estimate of the limit is that it is consistent with compliance with the 150-kiloton limit. Why then have claims of cheating been made against the Soviet Union? Two reasons.

First, the seismic signal of Soviet tests at their test site are larger than the seismic signals for U.S. tests with yields of 150 kilotons. The second reason is that the pattern of Soviet testing shows that the size of their tests increased after the first 2 years of the treaty. Let me explain these two arguments.

The validity of the first argument depends on how Soviet explosive yields are calculated. We test our nuclear weapons at the Nevada test site in the western United States. The Soviets test

theirs at Semipalatinsk in eastern Kazakh. Our test site, in the western United States is in a geologically young and active area. The area is being deformed by motion between the North American and the Pacific tectonic plates, and this recent geologic activity has created an area of unusually hot and possibly even partially molten rock beneath Nevada.

As a result when an explosion occurs at the Nevada test site, the deep underlying rock, which is warm and semi-molten, absorbs a large portion of the seismic energy. The Soviet test site, on the other hand, is in an area of the Soviet Union that would be more comparable to the eastern part of the United States. It is geologically old and stable. When an explosion occurs at the Soviet test site, the cold, solid rock transmits the seismic energy efficiently without absorbing much of it. As a consequence, seismic waves traveling from the Soviet test site appear much larger than waves traveling from an equal explosion at the U.S. test site.

The seismic community has reached a general consensus about what the correction should be to take into account these differences. Recently the actual yields of Soviet nuclear tests, as reported by the Soviets, have become available as part of the Joint Verification Experiments and can be compared with U.S. observations of the same tests. Although the true yields have not been independently confirmed, and only represents five tests, they do provide some insight as to whether this correction is appropriate. Classification prevents me from discussing the actual numbers, but I can say that the data are fully consistent with the analysis that was presented in the OTA report's discussion of Soviet compliance.

The second argument I mentioned is not a technical argument, but rather is based on assumptions about probable Soviet behavior. Two years after the signing of the Threshold Test Ban Treaty, the size of the largest Soviet explosions at their test site increased dramatically. There was speculation that the Soviets had discovered a change in our formula for calculating the size of their explosion which effectively reduced our estimates. They discovered this change, decided to take advantage of it, and so started testing at higher yields. The argument assumes that the change in U.S. yield estimation was in error, and that the Soviets have been testing in violation of the treaty ever since.

Alternative explanations for this apparent increase have also been offered. It has been pointed out that a similar pattern of testing also occurred at the test site for the two years prior to the treaty. It has also been speculated that the increase in yields reflected a Soviet decision to move their highest yield testing from their Novaya Zemlya test site in the Arctic to the Kazakh test site.

I would also add that as a further nontechnical consideration, it can also be argued that if the Soviets had tested above the limit of the Threshold Test Ban Treaty, they would probably not have offered to allow the United States to calibrate their test site using hydrodynamic methods and Soviet test explosions. The calibration will reduce the uncertainty of yield estimates and this reduction applies to past as well as future explosions and hence can provide a more accurate evidence concerning past compliance.

In light of the recent data exchanges, in-country seismic stations and on-site hydrodynamic methods, it is clear that there exists no

basis for accusing the Soviet Union of violating the 150-kiloton limit of the Threshold Test Ban Treaty. It is also apparent that means exists now to further limit the testing of nuclear weapons, should that be desired, and that brings me to my second issue: down to what level can we monitor testing within the Soviet Union (or the so-called "how low can we go" question).

Seismic monitoring networks are now extremely sophisticated and have remarkable capabilities. One must presume, however, that a country attempting to cheat would use every means to reduce the size of the seismic signal created by the explosion and fool the monitoring network. A seismic network must, therefore, demonstrate that it is capable of detecting and identifying seismic events with confidence despite any credible scenario for evasion. As the size of the explosion that you want to monitor becomes smaller, this task becomes increasingly difficult.

Given all the considerations, most experts believe that a high quality, well-run network of internal stations could monitor a threshold of somewhere around 5 kilotons. Expert opinion ranges from between 1 to 10 kilotons; the differences stem from differing judgments about what technical provisions could be negotiated within the treaty, how much the use of high frequency seismic signals will enhance our capability, and what levels of monitoring are necessary to give us confidence that the Soviets would not risk testing above the threshold.

The range of uncertainty also exists because we are extrapolating the performance of a hypothetical seismic network to areas where we have only limited data and experience. With the monumental work that has been done as part of the Joint Verification Experiments and agreements to place seismic instruments within the Soviet Union from other groups, such as the NRDC and IRIS, I predict that some of this remaining uncertainty will be reduced with time.

As you mentioned in your opening statement, how about the question of lower yields or a complete test ban? Such treaties could still be considered to be in the national interest if taking both seismic and nonseismic verification methods into account, the significance of undetected violations, if they were to occur, would be outweighed by the benefits of such a treaty.

In conclusion, I would just like to state that small differences of opinion concerning monitoring capability exist now and probably will always remain because a lot of the aspects of the debate are like comparing "half-full" and "half-empty" glasses of water. Some will review the complex burden and process of seismic monitoring and will conclude that a country would cheat if there is any uncertainty in any step of the process. Others will put the burden of certainty on the complicated evasion scenarios and conclude that when considering all means of intelligence, evasion is too difficult and risky to be credible.

The OTA report presents the range of opinion where technical consensus lies. Monitoring should be approached through a combination of seismic methods, treaty constraints, and inspections and any other methods that are acceptable, to provide the desired levels of verification. If such a combination approach is taken and appropriate supplemental provisions are negotiated within the

treaty, seismology can be very effective and low yields can be monitored with high confidence.

Thank you.

[The prepared statement of Dr. van der Vink appears in the appendix.]

The CHAIRMAN. Thank you, Dr. van der Vink. We'll hear from Dr. Nordyke next.

STATEMENT OF DR. MILO D. NORDYKE, PRINCIPAL SCIENTIST OF THE TREATY VERIFICATION PROGRAM, LAWRENCE LIVERMORE LABORATORY, LIVERMORE, CALIFORNIA

Dr. NORDYKE. Thank you very much, Mr. Chairman. I appreciate the opportunity to present my views on the current situation with the TTBT.

And I have some prepared remarks I would like to ask be inserted in the record.

The CHAIRMAN. They will be inserted in the record in full.

Dr. NORDYKE. Thank you.

I would also like to make it clear that I am speaking as an individual who has wrestled with some of these problems of negotiating and verifying treaties for the last 10 or so years, but not as a representative of the Lawrence Livermore Laboratory.

I think Ambassador Robinson has made it clear that a number of things have been happening over the last 2 years, the most exciting of which has been the JVE. And I would like to make a few comments on the Joint Verification Experiment and the implications that has for the future.

In my opinion the Joint Verification Experiment has been an extraordinarily useful event, and I think that is true from a number of different viewpoints.

First, it provided a unique opportunity for gaining insights into the logistical requirements and the operational aspects of doing an on-site measurement under a treaty monitoring regime which entails making measurements of yield. We obtained the first practical experience with the costs of such operations in terms of both the dollar and the manpower and the equipment resources that are required for such operations. Further, we gained some practical understanding of the interactions, both personal and organizational that will occur between such verification measurements and the program of nuclear weapons diagnostic measurements that under normal circumstances would be made as part of a nuclear weapons yield test.

I would like to say that from my point of view, that has been a very interesting aspect of the JVE because I was a member of the delegation that spent the better part of a year and a half in Moscow negotiating the terms of the Peaceful Nuclear Explosion Treaty which for the first time provided for on-site measurements of yield or of any sort of in-country verification. In that case we were talking about yield using the hydrodynamic method which has been implemented on the JVE.

During the development of those negotiations, we developed the language for how you would carry out the measurement, how you would handle the equipment, and that language has largely formed

the basis for what we have done in the JVE. And I must say that while we were writing and negotiating the language for those basic terms about equipment transfer and bringing in two sets of equipment and choosing one by random choice and all those ideas, we were constantly asking ourselves: "Is this really going to work in practice? Is it really going to be a very useful thing to do?" And I think the JVE has been a test bed for those ideas, and it has worked out I think quite, well, as Ambassador Robinson said.

In addition, the JVE provided an opportunity for the scientists of the two sides to interact at a technical level in a field situation where many of the artificialities and the constraints that are imposed by a negotiating environment were much less prevalent. For the first time the sides were able to learn in some detail how the other side carries out this common enterprise that we refer to nuclear weapons testing.

The JVE also demonstrated that the results are not always predictable as we like to think when we are dealing with experimental measurements.

The JVE underscored the fact that we must be prepared to deal with the results in a statistical framework, something which I think Dr. van der Vink made reference to specifically. And I believe that that is something that the U.S. has found hard, if not impossible, to do in the past.

Second, the JVE has demonstrated a Soviet willingness to accept verification measures that heretofore would have been regarded as unprecedented intrusions into their Soviet nuclear weapons testing program. Over 100 Americans have traveled to the Soviet test site with a comparable number of Soviets coming to the U.S. test site during this JVE exercise.

Most of the information that was called for in the 1974 TTBT protocol has now been exchanged for the two countries' high-yield testing areas. This is something that the Soviet Union had long refused to do before ratification of the treaty. As one of the earlier speakers made reference, the very fact of going there and making measurements was an act which many people within this government didn't believe would ever happen. So, the fact that the Soviets opened the test site up and let us come in I think was very significant.

Third, the JVE's have provided data that is relevant to the issue of Soviet compliance with the 150 kiloton of the Threshold Treaty. Even though the hydrodynamic yield and the seismic measurements constitute only one data point and, therefore, must be used with great caution, the range of opinion about the geophysical parameters involved in the estimation of yields at the Soviet test site has been so wide that even one data point is useful.

Specifically the key issue from a compliance point of view has been the existence or the nonexistence of a factor called magnitude bias, which Dr. van der Vink made reference to, for explosions at the Soviet test site relative to explosions at NTS. There are a number of geophysical and seismological studies that indicate that the seismic magnitudes from explosions at NTS are systematically reduced by a factor of between one-and-a-half and 3 in terms of yield relative to the magnitude for the same explosions if they

were carried out in Semipalatinsk. There are probably at least 20 studies which indicate that.

However, there are a number of people who simply don't believe that this factor exists and that it represents a concession that we are somehow making to the Soviet Union. They argue that we should use the same relationship between magnitude and yield for both test sites. This range of opinion within the policy community has made it very difficult to reach a consensus regarding the issue of TTBT compliance.

We now have a measurement of a yield of a nuclear explosion at the Shagan River test site with an on-site technique that is believed to be significantly more accurate than the current seismic yield technology and to have no bias of its own: the hydrodynamic technique that was defined in the PNE Treaty and implemented by the CORRTEX instrumentation.

We also have measurements of the seismic magnitude for this explosion. The USGS National Earthquake Information Service, who traditionally reports these kinds of things, measured a seismic magnitude of 6.1 for the Soviet JVE explosion. If that explosion had been fired at the Nevada test site, such a magnitude, 6.1, would have corresponded to a yield of over 350 kilotons if it were fired in the best rock we've got and even a larger yield if it had been fired in some of the poorer coupling rocks that we have at the test site.

I can't tell you what the yield was that was measured by the CORRTEX equipment at the Shagan River JVE, but I can assure you that if it had been anywhere near 350 kilotons, you would have read about it by this time in the New York Times or the Washington Post.

So, I think it is fair to say that this one explosion has established that there is a bias factor that must be applied before we can use the NTS data to estimate the seismic yields at the Soviet test site. And we are now only arguing about the value of the bias, not whether it exists or not.

One explosion is clearly not enough to do that with any certainty, but a fairly rudimentary statistical analysis shows that taking into account what we already know about the credible range of values for the bias, it can be reasonably well determined for a given test area at Semipalatinsk with three or four calibration explosions. Such a determination of the bias would reduce the overall error associated with the seismic yields to be significantly less than the oft-quoted factor of 2. If multiple seismic yields from each explosion were used for the seismic yield estimates instead of the one signal that currently is used, I believe that the overall error, after three or four calibration explosions at each testing area, would be somewhere in the range of 30 to 40 percent for explosions that are greater than 50 kilotons.

As I testified to this committee and to the Armed Services Committee last year, I believe that enhanced verification of the TTBT is needed before it is ratified. However, we should be cautious in our approach. It used to be that we knew the Soviet Union would reject almost all of our verification proposals at an early stage of the negotiations and argue for a minimum credible verification regime. And so we generally believed that anything that the Soviet

Union was willing to accept would be acceptable to the United States.

Today, however, I think as the INF Treaty clearly shows, it is a different world in the Soviet Union when it comes to treaty verification. Today she appears willing to accept almost any verification proposal made by the U.S. and then throw in a few ideas of her own. In that kind of a world, we must be much more careful than in the past to be sure that any verification regime we ask for will contribute to the long-term stability of our relationship as well as not work against our own vital interests.

With any verification scheme, there are costs and benefits which must be balanced. For the TTBT, the costs can be measured in terms of the dollars and the resources required, the interference and the diversion with our ongoing research and development programs and the possibilities of providing classified information to the other country on our nuclear design program. The JVE demonstrated that the dollar and the resource costs associated with such measurements will be substantial.

The operational interference and geometrical restrictions that must be imposed may well impact the design of our tests, such as nuclear directed energy weapons tests which have unique geometric arrangements. Inspections of the canisters of these tests to verify that treaty restrictions are being followed could well reveal sensitive design information, although measures, of course, will be taken to try to minimize such risks. The inherent openness of our society makes it much more difficult for us to limit the intelligence opportunities offered by the constant presence at each other's test sites that is inherent in the administration's proposals.

The benefits of a verification regime can be measured in terms of greater assurance regarding compliance, enhanced deterrence of an attempted evasion of the threshold limitation and opportunities for gaining information about the other country's mode of operation and decision making processes. Unfortunately, these are very vague and qualitative things and the comparison with the cost is difficult to do.

The CHAIRMAN. Excuse me. I think you are reading your whole statement, are you not?

Dr. NORDYKE. Yes, I am summarizing it.

The CHAIRMAN. I thought we were putting the whole statement in the record and you were summarizing it.

Dr. NORDYKE. Well, I just would like to say in conclusion that as I did a year ago that I continue to believe that the best balance for the costs and the benefits can be found in a regime of using calibration explosions rather than carrying out on-site verification of each and every test above some value. I think that such a regime will provide yield estimates for Soviet explosions with a significantly higher confidence and with smaller errors than at present while limiting the costs and other negative impacts on our own weapons program.

Thank you.

[The prepared statement of Dr. Nordyke appears in the appendix.]

The CHAIRMAN. Thank you very much, Dr. Nordyke.

We have come to Professor Hafemeister.

STATEMENT OF DR. DAVID W. HAFEMEISTER, PROFESSOR OF PHYSICS, CALIFORNIA POLYTECHNIC STATE UNIVERSITY, SAN LUIS OBISPO, CALIFORNIA

Dr. HAFEMEISTER. Thank you, Mr. Chairman, for the opportunity to testify on the verification and compliance of the TTBT. From January to December 1987, I was the technical lead for the Department of State on the TTBT interagency work program. Since that time, I have returned to my position as professor of physics at California Polytechnic State University.

In my remarks today I would like to focus on just two issues: one, the compliance decision; and two, the compliance-judgment process within the executive branch.

The compliance decision is vastly different than a policy decision in that it is judicial in nature and involves such issues as:

One, what did the law or, in this case, the treaty say?

Two, what is the evidence?

Three, is the same standard of evidence applied to both sides in a consistent manner?

Four, who decides that evidence is inadmissible and that standards are consistent?

Five, does the treaty partner have an advocate, or at least a position paper, which will present his side no matter how unpopular?

In my testimony I will indicate that the compliance process in the executive branch has not always been a judicial process since the third, fourth and fifth criteria have been violated. When one examines the Soviet noncompliance charges against the U.S., the same questions can be asked of the Soviets. My intent today is not to belabor the errors of the past, but rather how can we do better in the future. It is my belief that the process for compliance decisions must be treated differently than the normal process for policy decisions. If arms control is to have a future, we must develop more judicial internal procedures to enhance the fairness of the compliance process.

In my testimony I will offer some suggestions to improve the compliance process that could be considered by the next administration which has the responsibility to carry out the compliance-judgment process, the next Congress and by the Soviet Union.

First, let's take the compliance with the TTBT: While at the State Department, I examined the relative data from all the interagency working groups involving both seismic and other data. In particular, I carried out a thorough statistical analysis of the seismic data, taking into account the random and systematic errors and using the accepted U.S. Government value for the bias factor.

I agree with the Defense Intelligence Agency report of 1985, which has been cited in the OTA report; the letter from Dr. Batzel of Livermore Labs to you, which I presume is in the record; and other internal studies that the seismic data sets are the most meaningful for the present consideration of the past Soviet compliance with the TTBT. In the future when the calibrations of the test sites are completed, the systematic errors in the seismic data will be reduced, and at that time the data should be reexamined.

Since all the measured yields of the largest Soviet tests fall within statistical uncertainties of measurements centered at ap-

proximately 150 kilotons, it appears that the Soviets are complying with the limit of 150 kilotons. If one applies the same standard of evidence to the testing programs of both the U.S. and the USSR, one can state that both sides are complying to the TTBT within the accuracy of the measurements. Because of the statistical uncertainties, one cannot rule out that a very few Soviet or American tests may have exceeded 150 kilotons by only a small amount. But when one considers the distribution of the tests, this does not constitute a violation. Thus, it is incorrect to state, as it does in the President's report to the Congress on Soviet noncompliance, that the Soviet nuclear tests are a likely violation.

Furthermore, virtually all the technical people at the working level analyzing these data in other agencies reach the same conclusion.

If one is to claim noncompliance, one must assert one of the following two approaches:

Errors in the bias factor. We have already heard some discussion on that, so I think I will abbreviate this part of the discussion. But I would just like to make a point that if one ignores the systematic error in the bias—in other words, if you pick a point, point X, and you don't say plus or minus, then in effect you are reducing the apparent F factor, which is used in the statistics, and you will make some points creep outside above the error bars. And that is making a very large error in one's statistical analysis. So, that is one way that one can come up with noncompliance, and it is totally wrong.

The other way that one can come up with noncompliance is the area of nonseismic data on Soviet tests. And I have already indicated that there is a letter from Dr. Batzel, which I have quoted in my testimony and I presume is part of the hearing record, in which he says—I'll just take one part of it—"Our conclusion, like that of the DIA panel which also reviewed all the data, is that the seismic evidence is currently the most reliable basis for estimating the yield of Soviet underground nuclear explosions." And the OTA report and the internal studies—just about everybody agrees with that.

From what I know about the data, the Livermore and OTA conclusions are correct. I have done independent calculations on the compliance and calibration data. I have participated in the groups that analyzed the nonseismic data. I have spent a considerable amount of time with scientists at the working level on all these technical issues. From my work and these discussions, I find great unanimity among the scientists on the conclusions on compliance by OTA and Livermore.

On the other hand, I take great exception to the executive branch testimony before the House Foreign Affairs Committee on June 28, 1988 that states: "Furthermore, the totality of evidence strengthens"—underline the word "strengthens"—"the previous finding of likely TTBT violation." This statement implies that the nonseismic data were good enough to prove the case, which is in disagreement with DIA, OTA and other internal reports.

The most recent report to the Congress on Soviet noncompliance by Dr. Barker in the House also on June 28 stated that: "While in view of ambiguities in the pattern of Soviet testing and in view of verification uncertainties, the available evidence is ambiguous and

we have been unable to reach a definitive conclusion, this evidence indicates that Soviet nuclear testing for a number of tests constitutes a likely violation of legal obligations under the TTBT."

A likely event must be much more probable than a not likely event. The concluding charge of a likely violation in this sentence does not logically follow from the preamble portions of the sentence. One can only conclude that the executive branch must have been split over the issue and that the National Security Council attempted to patch the disagreement together.

One can then ask the question, "why has the executive branch maintained the charge of likely violation?" My conclusion is that the likely violation charge would not be made now except for the momentum of past noncompliance charge. In my longer statement, I go into that in more historical detail.

Now to the most important part, part II, the compliance judgment process. How can the interagency compliance process be improved? I will now discuss a proposal for the U.S. and the Soviets.

The last part of my testimony is not based on science, but rather is intended as a provocative suggestion in order to have us focus on the improvement of the compliance process. My suggestions, rather than criticisms, are relevant to both sides since both sides have on occasion made charges that are stronger than the data warrants. Thus, my suggestions are relevant to both sides.

Let us admit that we both can improve and leave it at that. Within this spirit, I will offer the following three possible rules of conduct for compliance deliberations in the internal proceedings of the U.S. and in the Soviet Union in order to carry out criteria 3 to 5 listed in the first paragraph.

One, the same standard of evidence shall apply when considering U.S. charges of Soviet noncompliance and, two, U.S. compliance with the same treaties. We should encourage the Soviets also to apply the same standards to the two situations they face.

Two, the interagency group as a whole shall rule on the validity of standards of evidence with disagreements directly appealable to the National Security Council. What happens in practice is that some evidence is downgraded, and everybody agrees it is not very good. But then when they report to the NSC, the agency then throws in this data that nobody believes in. And the NSC staff, not knowing the details, will then look at that thread, and so bad threads go forward.

Three, the treaty partner, which is not in attendance to present its views, shall be represented by either an interagency paper representing their views, or preferably by an experienced advocate appointed by the President or his designate. It is the responsibility of the advocate or position paper to argue against unreasonable positions and ask hard questions of the other agencies. This process should encourage the executive branch to ask treaty partners additional questions which might or might not clarify the situation. We should encourage the Secretary General to appoint an American advocate so that their ridiculous charges also can be swept away from the Soviet internal compliance proceedings.

Can these rules be implemented? No matter which political party controls the executive branch, it is unlikely that the executive branch will want to consider formalizing their compliance judg-

ment process for fear of infringement by the Congress on their national security process. It is very unlikely that the Congress can dictate the details of the classified national security process.

However, the Congress should require the executive branch to report back on a study of rules of fairness, consider other improved procedures and examine the possibility how they can implement these ideas in their process. Right now there are, as one can guess, very few rules. I do not know a rule book that one can point to for these proceedings.

Without some action along these lines, some of these problems will continue such as:

One, in the past, two different standards have been used on at least two occasions that I know personally which required a higher standard from the Soviets than from the United States. A judicial process demands the same standard.

Two, because the six agencies in the compliance process don't wish to be viewed as too favorable toward the Soviets, it becomes somewhat difficult to combat unreasonableness and ask hard questions like, "did you really calibrate that," and so forth.

Three, where there are many issues at the interagency process, defending due process for the Soviets becomes expendable.

Thank you very much, Mr. Chairman. I will gladly answer questions.

[The prepared statement of Dr. Hafemeister appears in the appendix.]

The CHAIRMAN. Thank you very much indeed, Dr. Hafemeister.

I'd like to ask I guess Dr. van der Vink, putting it very simply, are seismic methods better or worse than CORRTEX? "Better or worse" is not the right phrase, but more accurate or less accurate. Which do you prefer?

Dr. VAN DER VINK. Well, CORRTEX is stated to have an accuracy of within a factor of 1.3. in other words, it is supposed to be accurate within 30 percent.

A conclusion of our study was that if advanced seismic methods were used and the Soviet test site was calibrated—as Dr. Nordyke mentioned, several calibration shots would be needed—seismic methods can also estimate yields with a comparable uncertainty (around a factor of 1.3 also). This conclusion is not theoretical. In fact, it is based on experience. We currently estimate explosive yields at our own test site within a factor of 1.3 using seismic means.

The problem is that the Soviet test site has not yet been calibrated, and it would need calibration shots. In this area, CORRTEX could be useful as a means for independently confirming the yields of the calibration shots.

The CHAIRMAN. If that were done, wouldn't that then mean that with seismic methods we would be able to know what the Soviets were doing in testing without having any intrusive inspection of people on their soil?

Dr. VAN DER VINK. Yes, I would agree with that.

The CHAIRMAN. Once the field had been calibrated.

Dr. VAN DER VINK. Sure, yes. And I think, as Dr. Nordyke mentioned, one can look at these Joint Verification Experiments and the use of CORRTEX as short-term calibration process for seismic

methods. It could be a calibration process of short duration until we have reduced the error in the seismic methods to a comparable amount.

The CHAIRMAN. Did you find in your work that there is a difference in how each side measured the yields, or was it pretty much the same?

Dr. VAN DER VINK. Well, that brings up actually a subtle and rather interesting issue. I would just like to add, though, before I address that question, we have also heard from the Soviet scientists that they are able to estimate the yields of their own tests at their own test site within 20 percent, a factor of 1.2. So, that is a further indication that we should be able to achieve with seismic methods the same yield estimation capability as CORRTEX.

The term that we use for describing the explosive power of a nuclear explosion is a "kiloton" which originally was defined as the explosive power equivalent to 1,000 tons of TNT. This definition was found to be imprecise because there were differences in the theoretical and experimental values of how much energy was actually released by 1,000 tons of TNT. Also, a kiloton could refer to a metric ton, a short kiloton, or a long kiloton? I think at one time they even had a reference to what was called the "California kiloton" because people at Livermore measured it slightly different than the people at Los Alamos. So, during the Manhattan Project, they adopted a definition where a kiloton was equal to the release of 10 to the 12th calories of explosive energy. It is my understanding that the same definition is used by the Soviet Union.

The problem is that when we calculate the yield, we only refer to the energy that is released immediately, what is called the "prompt energy release" of the explosion. And there does not seem to be any general precise definition about what time frame is considered prompt. As a result, it is not certain that, in fact, the Soviets measure a kiloton in the exact same way we measure a kiloton. I would estimate, though, that any differences that existed would not be greater than, say, 5 percent. So, there may be slight differences just attributable to that fact alone.

The CHAIRMAN. In your view the Soviets have complied with the TTBT?

Dr. VAN DER VINK. I certainly agree with Professor Hafemeister. The pattern of Soviet testing is similar to ours. All Soviet tests are within the 90 percent confidence level that you would expect if they were complying. Statistical stdies indicate that they are oberving a yield limit consistent with compliance. If the Defense Intelligence Agency's review panel is correct in their statement that seismic means are the best means of the yield estimation, then there is no basis for the charge of noncompliance.

The CHAIRMAN. Thank you very much.

Dr. Nordyke, I would like to ask the same question to you; that is, do you believe that seismic monitoring—what would be your comment on the press report that seismic monitoring out-performed the CORRTEX at the joint experiment?

Dr. NORDYKE. Well, I don't think I would agree with that statement that seismic out-performed CORRTEX on the JVE. They were independent measurements. We are still in the process of

comparing them. They didn't give us the same results at both sites, and we're still trying to make sense out of how they do compare.

I think in respect to the question of how do they compare in general, I would just add to a point Dr. van der Vink made that making CORRTEX measurements on weapons tests is not free in the sense that it does restrict what you can do in the nuclear weapons test. It does impose significant costs. It does require you to write restrictions on the geometries, and then those restrictions have to be inspected. And so, it represents a significant amount of interference with the ongoing program.

So, doing it on every weapons test represents a long-term tax, you might say, that you have imposed on the weapons program in this process; whereas, seismic—once you have it calibrated, once you have made the capital costs of calibrating it, then it is a measurement system which doesn't have an annual tax.

Also, as you go down in yield to lower yields, it becomes more and more difficult to enforce the geometrical restrictions you need in order to have good CORRTEX measurements. There is no reason in theory why you can't have an explosion well monitored by CORRTEX, but the practical realities of making the measurement, diagnostic canisters and all that, start to get in the way in a very serious manner as you go down in yield. And so, at lower yields seismic calibration is much more attractive than doing CORRTEX on every weapons test.

The CHAIRMAN. From the previous testimony, it was easier for testing to be done in the Soviet area where the rocks were stable as opposed to Nevada where you have the instability or hotness of it. That would mean that presumably if we had relied on seismic methods, we would have a certain edge if each side kept its own present field.

Dr. NORDYKE. Well, we have to recognize—and I think we are slowly making progress making everybody recognize— that there is this difference between our two test sites and that we do have to treat the seismic magnitudes from events at the Soviet test site in a different way than we do seismic magnitudes from our own test site.

The CHAIRMAN. That would come up in the calibration.

Dr. NORDYKE. Yes. And that is why, in order to convince everybody, I think the calibration explosions are the most straightforward way to do that.

The CHAIRMAN. On the other hand, CORRTEX would be the same in both fields.

Dr. NORDYKE. Well, we believe it would. To the extent that we understand the process, so long as the rock type that we are dealing with is one that falls within our experience base, we think that we would understand how to interpret the CORRTEX measurement.

I should make the point that the CORRTEX measurements have all the same kinds of errors, systematic and random, that seismic does. In general, they are believed to be smaller.

The CHAIRMAN. In your statement, Dr. Nordyke, I believe you are saying that we may be seeking more extensive and intrusive verification than we need in the testing talks. Are you saying that

we have not done as well as we should in weighing the disadvantages of our various verification proposals?

Dr. NORDYKE. Well, as I said, my own feeling, my own belief, is that calibrating the Soviet testing areas is absolutely essential under any circumstances. And when you combine that with seismic, and when you use seismic in the most responsible way, where you use all of the seismic data that you have available to you, not just part of it, as we presently do—then I think the errors in the seismic yields will be made sufficiently small that the benefit realized from that will be more than offset by the costs that you are undertaking by doing CORRTEX measurements on every weapons test as an alternative.

The CHAIRMAN. Thank you very much.

I would like to ask Professor Hafemeister his view as to whether there was any technical basis for the judgment of the administration in 1987 when they reported the Soviets were in likely violation of the TTBT.

Dr. HAFEMEISTER. In my own calculations, which I did independently, I find that one cannot make the likely violation charge. All of the largest events fit within the error bars defined by the statistical factor, none of them falling outside, that I see no basis for the "likely noncompliance charge". And I was further strengthened in that in that I went out and talked to the people who did full-time statistics, the people in the labs,where as I put a year's work into it and worked as hard as I could and as brightly as I could. I went to the scientists who were removed from the political process and talked to them, those who could teach me a few things. And I found a great deal of unanimity among the serious scientists on this.

The CHAIRMAN. What do you think would have been a fair assessment of Soviet compliance?

Dr. HAFEMEISTER. The sentence I had in my testimony said that, within the accuracy of the measurements, both the U.S. and the Soviets are complying with the TTBT.

The CHAIRMAN. Thank you very much.

Senator Pressler?

Senator PRESSLER. Thank you very much, Mr. Chairman. And I shall read this with great interest as well as the questions and answers. I apologize for being late here having two or three assignments going on simultaneously.

I would like to ask two questions of any volunteers on the panel who might want to comment. Even with the joint experiments, the exchange of data and direct on-site measurements is it possible that we will never be able to determine conclusively that previous Soviet tests have been within the limits of the Threshold Test Ban Treaty?

The CHAIRMAN. All right, Dr. Nordyke?

Dr. NORDYKE. That reminded me of something which I was going to say but didn't on the advantage of seismic—the idea of a calibrated, improved seismic over the measurement of the yield of every test. Development of an improved seismic estimation technique does make it possible to go back and look at all the past events and see whether or not the issue of compliance has been—whether compliance has been realized or not.

If you don't take the improved seismic methodology which has been developed and implement it, if we let seismic yield estimation continue to use only the old type of estimation that they have been using, just using a single seismic yield estimation technique, then we will never be able to go back and check the issue of compliance or noncompliance for these past events.

So, I think it is very important that we implement the new methodology, and if we do implement the new one and have it calibrated, then I think we would be in a position to go back and evaluate those past events as well as the future.

Dr. SHARFMAN. Mr. Chairman?

The CHAIRMAN. Mr. Sharfman?

Dr. SHARFMAN. If I might add briefly a point there. It does depend a little bit on what you mean by conclusively. It would be possible to go back over the past record and say that there are very strong indications that the Soviets had complied and there was an absence of persuasive indications that they had not complied. But that is not quite the same thing as conclusive proof that they have complied. And unfortunately, the whole area of verification involves the kind of probabilistic and statistical measures where you can get any degree of confidence you think you need, but you can never get 100 percent confidence.

The CHAIRMAN. Thank you very much.

Professor Hafemeister?

Dr. HAFEMEISTER. Another question one has to raise, since you can never get total, absolute certainty because we are dealing with the distribution function, is in a paragraph which I have in my testimony, which I did not read. It is called, "How Much Verification Is Enough? A Sensitivity Analysis Of The Threat To National Security Due To A Breakout From The TTBT." In this paragraph I indicated that I did calculations in the published literature in 1984 and then also in the government with classified data bases using exchange models. Basically one has to ask how militarily important is a breakout of, say, 10 or 20 or 30 kilotons.

And at the same time I also did a variation of parameters on accuracy and reliability. And just about everybody agrees with the answers in my unclassified paper, which I did before I went to the government, and the same results I got from the government, is that variations in yield are much, much less important as compared to variations in accuracy or reliability. I concluded that vbariations in the yield are the third most important variable when you start talking about the killing of hard targets.

So, one has to look at those kinds of studies when you decide which verification technology you want. Then it is a policy judgment as to whether you think it is important or not.

The CHAIRMAN. Thank you.

Senator PRESSLER. Now, the administration has charged the Soviet Union with repeated violations of the 1963 Limited Test Ban Treaty. Will the new verification protocols help to limit violations of the Limited Test Ban Treaty?

Dr. NORDYKE. Not in and of itself. I don't see that it would. The only improvement would be that there would be increased presence by the U.S. representatives—virtually continuous presence—at the Soviet test site which would perhaps impose psychological pressure

to do a better job of compliance, but I think there is nothing in the treaty provisions that do that —anticipated treaty provisions.

Dr. HAFEMEISTER. By violation in this case, you mean venting I presume. Is that what you meant, Senator Pressler?

Senator PRESSLER. Yes, that is correct.

Mr. Chairman, I have no further questions. I may have a question or two for the record.

The CHAIRMAN. The record will stay open for three days for the submission of questions by any member of the committee.

There is one further question I would like to ask and that is assuming the verification protocols are concluded, what do you see as the kinds of further testing restraints that could be effectively verified. Dr. van der Vink?

Dr. VAN DER VINK. There certainly have been a lot of proposals for various different restrictions of testing: quotas, low yields, comprehensive, etc. I think to a great extent, what can be verified depends on what provisions can be negotiated. Verification is a long equation with many variables: the number of seismic stations, testing restrictions, on-site inspections, etc. Depending on the combinations you can obtain different levels of confidence for monitoring different thresholds.

Also, a lot of this discussion once again gets back to the half-full half-empty question. We found in situations where even when people agreed that monitoring could be done at say, 5 kilotons, some people would say, okay, that means we need a 10-kiloton treaty to really make sure, and other people would say, oh, that means we can have a 1 kiloton treaty because if anyone was going to test, they would test at 5 and we would discover that. So, there is always that sort of inconsistency.

What we found in our research given all these considerations, is that most experts believe that a threshold down to around 5 kilotons could be monitored with high confidence. There is certainly no problem above 10 kilotons, and there certainly are big problems below 1 or 2 kilotons. And as you mentioned, a comprehensive test ban treaty could be considered verifiable, if the decision is made, that the risk of any small infraction would be outweighed by the benefits of the treaty.

The CHAIRMAN. Thank you very much.

Did you want to say something?

Dr. NORDYKE. I just would like to add a bit to that issue. Certainly if you are going to go down, I believe that you could go to yields in the 5 to 10 kiloton range with an accuracy which is not much degraded over what we presently would be able to do at the 150 kilotons if we get the same kinds of seismic phases—in other words, by putting in internal seismic stations. I think you could only do that if you put internal seismic stations into the Soviet Union in order to get additional seismic phases that we cannot get outside the country for yields of the order of 10 kilotons.

Those stations in the Soviet Union would then give us not only information on those tests, but also information on the general propagation of seismic waves in the Soviet Union which would fill a very big hole in our understanding of the general problem of seismic verification of both low thresholds and even of comprehensive test bans.

The CHAIRMAN. Thank you very much. We will keep the record open for an additional 2 weeks so witnesses and individuals can submit additional material for the record.

This meeting of the Foreign Relations Committee is adjourned.

[Whereupon, at 11:28 a.m., the committee was adjourned subject to the call of the Chair.]

APPENDIX

Testimony for Ambassador C. Paul Robinson
Before the Senate Foreign Relations Committee
October 6, 1988

Mr. Chairman and members of the committee, I am pleased to have the opportunity to update you on the status of our work in Geneva in the nuclear testing talks with the Soviet Union.

We are presently in the 6th week of Round III of these talks. Round I was an initial two week session last November to organize the talks and prepare for familiarization visits by US and Soviet experts to each side's nuclear test site. These visits were conducted in January of this year.

Round II began on February 15 and was a marathon session, extending until June 28. In this session, we negotiated a detailed agreement for a Joint Verification Experiment (JVE) in which each side would conduct a nuclear test at its site, with the other side bringing verification instruments based on hydrodynamic methods to measure directly the yields of the tests. The JVE agreement was signed at the Moscow Summit on May 31.

Also in Round II, we began parallel negotiations on new protocols to the 1974 treaty to the limitation of underground nuclear tests, popularly known as the Threshold Test Ban Treaty

(TTBT), and to the 1976 treaty on underground nuclear explosions for peaceful purposes usually referred to as the Peaceful Nuclear Explosions Treaty (PNET). The Treaties, negotiated more than a dozen years ago, have never been ratified by the sides.

Both sides have agreed that the present negotiations will not result in changes to the treaties themselves. Rather, we are negotiating a new protocol to each treaty which will provide effective verification measures which can allow these treaties to be ratified.

At the end of Round II, we had completed a joint draft text of the PNET Protocol and each side had tabled separate drafts for the TTBT Protocol. The Soviet Union had insisted that the JVE tests be completed and analyzed before finalizing language on language on verification measures for the TTBT protocol.

I am pleased to report to you today that substantial progress has been achieved in our work this year. Both JVE tests have been successfully conducted according to the plan and schedule we negotiated. The explosion in the US took place on August 17 at the Nevada Test site. The explosion in the Soviet Union took place on September 14 at the Semipalatinsk Test Site.

The experiments were both enormously successful, and I believe they will prove to be equally useful as we draft the final text of the new protocols.

Both the US and the Soviet equipment performed well in recording the data related to the yields of the tests at both sites. Exchanges of the data recordings and preliminary analyses show only small differences in results for the hydrodynamic measurement methods. I am pleased to note that the uncertainties associated with the events are much less than the 30 percent value we have always assigned for CORRTEX, the US hydrodynamic method. In a word the JVE successfully demonstrated the effectiveness and practicability of the CORRTEX method which the US requires for effective verification of the Treaties.

There were also important practical lessons learned by both sides in the course of conducting these on-site verification activities. There were problems which arose, as there always are in such complex undertakings, but the sides maintained a business-like, problem-solving approach throughout the effort.

The Joint Verification Experiment was doubtlessly an important step in Soviet-American relationships in arms control and has, in addition to its technical value, served as a useful

confidence-building measure. I remain confident that we can continue to build on these successes to complete the task of the first stage of these step-by-step negotiations on nuclear testing, the successful ratification of both treaties. This done, we will immediately propose negotiations on ways to implement a step-by-step parallel program -- in association with a program to reduce and ultimately eliminate all nuclear weapons -- of limiting and ultimately ending nuclear testing.

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STATEMENT OF DR. GREGORY E. VAN DER VINK
Project Director

Office of Technology Assessment
Congress of the United States

Testimony Before the

UNITED STATES SENATE
COMMITTEE ON FOREIGN RELATIONS

on

SOVIET COMPLIANCE WITH THE NUCLEAR TESTING TREATIES

October 6, 1988

Good morning. It is a pleasure to appear before the Committee. I am Dr. Gregory van der Vink, project director for the Office of Technology Assessment's study, *Seismic Verification of Nuclear Testing Treaties*.

In my testimony today, I will cover two questions addressed by our study:

1. Has the Soviet Union violated the 1974 Threshold Test Ban Treaty?

2. Down to what size explosion can we seismically monitor within the Soviet Union?

First, let me address the issue of treaty compliance:

I. SOVIET COMPLIANCE WITH THE 150 KT LIMIT OF THE THRESHOLD TEST BAN TREATY

THE TREATIES

The 1974 Threshold Test Ban Treaty (TTBT) restricts the testing of underground nuclear weapons by the United States and the Soviet Union to yields no greater than 150 kilotons. The 1976 Peaceful Nuclear Explosions Treaty restricts individual peaceful nuclear explosions by both countries to yields no greater than 150 kilotons and aggregate yields no greater than 1,500 kilotons.

Although the 1974 Threshold Test Ban Treaty and the 1976 Peaceful Nuclear Explosions Treaty have remained unratified for over 10 years, both nations have expressed their intent to abide by the yield limit. Because neither the United States nor the Soviet Union has indicated an intention not to ratify the treaties, both parties are obligated under international law to refrain from acts that would defeat their objective and purpose.[1]

THE COMPLIANCE CONCERN

Questions concerning Soviet compliance with test ban treaties have arisen with findings by the Reagan Administration that:

"Soviet nuclear testing activities for a number of tests constitute a likely violation of legal obligations under the Threshold Test Ban Treaty."[2]

In examining compliance with the 150 kiloton threshold, seismic evidence is currently considered the most reliable basis for estimating the yields of Soviet underground nuclear explosions.[3] Consequently, it is the interpretation of the seismic data that controls the compliance debate.

1Article 18, the 1969 Vienna Convention on the Law of Treaties.

2For example: "The President's Unclassified Report on Soviet Noncompliance with Arms Control Agreements," transmitted to the Congress, March 10, 1988.

3Conclusion of the Defense Intelligence Agency Review Panel as stated in a letter from Roger E. Batzel, Director of Lawrence Livermore National Laboratory to Senator Claiborne Pell on February 23, 1987.

UNCERTAINTY AND THE COMPLIANCE ISSUE

Yield estimation is a statistical measurement. Consequently, the question of compliance should not be addressed by looking at individual tests, but rather by examining the pattern of Soviet testing. A clear illustration of the potential danger of looking at an individual test occurred during the recent Joint Verification Experiments. As part of these experiments, the United States invited several dozen Soviet scientists to the Nevada test site to witness the use of the on-site CORRTEX method of yield estimation. CORRTEX has been proposed by the United States as a means for improving verification of the 150 kiloton limit of the 1974 Threshold Test Ban Treaty. As reported by the Washington Post on September 8, 1988 (Attachment 1), the CORRTEX system measured the yield of the test explosion as being around 155 to 163 kilotons, an apparent violation of the 150 kiloton limit. The Post article included statements from U.S. officials saying that the test was not a violation and that the true yield was approximately 145 kilotons. Ambassador Paul Robinson was quoted as saying "the test was clearly below the [treaty] limit."

The CORRTEX measurement above 150 kilotons for the U.S. test does not mean that the United States violated the treaty, nor does it mean that CORRTEX is an inadequate method of yield estimation. If the Post story is in fact accurate, CORRTEX performed well within its advertised capability. It is the nature of this type of measurement that if testing occurs up to the yield limit, some measurements of those tests will give results slightly above the yield limit. As the Joint Verification Experiment demonstrates, no method of yield estimation is exempt from uncertainty.

ADDRESSING THE COMPLIANCE QUESTION

What would be most useful to Congress would be a definitive answer as to whether the Soviets have cheated. Yet as we have seen, every method of yield estimation has some uncertainty associated with it. This, however, does not mean that the treaty is unenforceable. Consider as an analogy the monitoring of the automobile speed limit. The police use radar measurements to catch drivers exceeding 55 mph. Under the 150 kiloton limit, an observed yield of 160 kt (as in the recent JVE experiment) is like a radar reading of 58.7 mph under a 55 mph limit. The police generally do not give tickets when their radar shows a speed of 58.7 mph because most speedometers are not that accurate or well calibrated, and because curves and other factors can lead to small uncertainties in radar estimates of speed. Similarly, a 160 kt measurement should not be regarded as a legal lack of compliance because such a number can well arise from uncertainties in in the measurement technique -- whether it be CORRTEX, seismic, or radiochemical. At radar measurements over 65 mph the police do not question that the 55 mph limit has been exceeded, and the speeder gets a ticket. At this level of accuracy it would take a calculated yield of about 180 to 190 kt to conclude that a violation had likely taken place.

It should be emphasized, however, that this argument does not mean the Soviets could take advantage of the uncertainty and test up to 180 to 190 kilotons. The uncertainty could just as likely work against them. A 180 to 190 kt test might produce an observed yield well over 200 kt, which would be a clear violation.

Obviously, the calculated yield for declaring a treaty violation will be higher than the limit of the treaty. Consequently, one or two small breaches of the treaty could occur within the expected uncertainty of the measurements. A country intent on cheating might try to take advantage of this by risking one or two tests above the limit, just as a driver might risk driving slightly above 55 mph on the assumption that neither his speedometer nor the radar measurement will be high and so he can take advantage of the uncertainty. Even if detected, a rare violation slightly above the threshold could be explained away as an accidental violation due to an incorrect prediction of the precise yield of the nuclear test. Such accidental violations are accepted by the treaty's so-called "whoops" consideration that accounts for slight accidental breeches of the limit. However, when negotiating a treaty, the threshold should be chosen carefully to ensure that small violations of the chosen threshold (whether apparent or real) do not fall in a range that is perceived to be militarily significant -- e.g. one where the ability to test just above a particular threshold confers military advantage compared to not testing above that threshold.

JUDGING COMPLIANCE

As the previous discussion has illustrated, there will always be uncertainty in any method of yield estimation. The argument can always be made that a particular test could have been, for example, 153 kilotons rather than 150 kilotons. Consequently, the question of compliance is addressed best by examining the entire pattern of Soviet testing.

Since the signing of the Threshold Test Ban Treaty in 1974, the Soviet Union has conducted over 200 underground nuclear explosions. The seismic data indicates that about 10 of these tests could have estimated yields above the 150 kiloton threshold limit. However, when the same method of yield estimation is applied to the U.S. tests, approximately the same number of U.S. tests also appear to be above the 150 kiloton threshold limit. Both results would be expected if neither country had exceeded the yield limit.

All of the estimates of Soviet tests are within the 90 percent confidence limit that one would expect if the yields were 150 kilotons or less. Statistical studies of the distribution of estimated yields of explosions at the Soviet test site conclude that the Soviets are observing a limit. The best estimate of the limit is that it is consistent with compliance with the 150 kt limit of the Threshold Test Ban Treaty. Why then have claims of cheating been made against the Soviet Union?

THE BASIS FOR THE COMPLIANCE CONCERN

Allegations that the Soviet Union has violated the treaty are derived from two arguments:

1. The seismic signal of Soviet tests at their Shagen River test site are larger than the seismic signals for U.S. tests with yields of 150 kilotons.

2. The pattern of Soviet testing shows that the size of their tests increased after the first two years of the treaty.

The validity of the first argument depends on how the explosive yields are calculated. It is well known that the geophysical characteristics of the Nevada test site differ greatly from those of the Soviet test site. The western part of the United States is a geologically young and active area that is being deformed by the motion between the North American and Pacific tectonic plates. This recent geologic activity has created an area of unusually hot and possibly even partially molten rock beneath the Nevada test site. As a result, when an explosion occurs at the Nevada test site, the deep underlying rock absorbs a large portion of the seismic energy. The Soviet test site, on the other hand, is more similar to the geology found in the eastern United States. It is a geologically old and stable area, away from any recent plate tectonic activity. When an explosion occurs at the Soviet test site, the cold solid rock transmits the seismic energy without absorbing it. As a consequence of these geologic differences, seismic waves travelling from the Soviet test site appear much larger than waves travelling from an

equal explosion at the U.S. test site. Hence, a larger signal from the Soviet test site does not necessarily mean that a larger explosion has been detonated.

The seismic community has reached a general consensus about what the value of the correction should be. Recently, the actual yields of Soviet nuclear tests, as reported by the Soviets, have become available as part of the Joint Verification Experiments and can be compared with U.S. observations of the same tests. Although the true yields have not been independently confirmed, and only represent 5 tests, they do provide some insight as to whether this correction is appropriate. Classification prevents me from discussing the actual numbers, but I can say that the data are fully consistent with the analysis presented in the OTA report's discussion of Soviet compliance.

The second argument is not a technical argument but rather is based on assumptions about probable Soviet behavior. Two years after the signing of the Threshold Test Ban Treaty, the size of the largest Soviet explosions at their eastern Kazakh test site increased markedly. There was speculation that the Soviets had discovered a change in the official U.S. method of yield estimation and had taken advantage of it. The increase has been interpreted by some to mean that the Soviets were testing up to the limit for the first two years, discovered the reduction in U.S. yield estimates due to the new method, and subsequently started testing at higher yields to take advantage of it. The argument assumes that the change in U.S. yield estimation was in error, and that the Soviets have been testing in violation of the treaty ever

since. Alternative explanations for this apparent increase have been offered. It has been pointed out that a similar pattern of testing also occurred at Kazakh for the 2 years prior to the treaty. It has been further speculated that the increase in yields reflects a Soviet decision to move their higher yield testing from the Novaya Zemlya test site to the Kazakh test site.[4] As a further non-technical consideration, it can also be argued that if the Soviets had tested above the limit of the Threshold Test Ban Treaty, they would not have offered to allow the United States to calibrate their test site using hydrodynamic methods and Soviet test explosions. The calibration will reduce the uncertainty of yield estimates, a reduction that applies to past as well as future explosions and hence can provide more accurate evidence concerning past compliance.

In light of the recent data exchanges, in-country seismic stations, and on-site hydrodynamic measurements, it is clear that there is no basis for accusing the Soviet Union of violating the 150 kiloton limit of the Threshold Test Ban Treaty. It is also apparent that the means exist to monitor the Threshold Test Ban Treaty with confidence in the future. As Dr. Sharfman mentioned, verification as distinct from monitoring is a political process. Whether data exchanges, seismic analysis, and CORRTEX establish Soviet compliance is ultimately a political decision about what levels of uncertainty are acceptable.

4See for example, "Nuclear Test Yields" (letter to the Editor), J. F. Evernden and L. R. Sykes, *Science*, vol. 223, Feb. 17, 1984, p. 642.

II. HOW LOW CAN WE GO?

Seismic monitoring networks are now extremely sophisticated and have remarkable capabilities. For example, a high quality network could detect and identify with confidence nuclear explosions well-below 1 kt, if no attempt were made to muffle the seismic signal or spoof the seismic network. Figure 1-1 of our report shows the seismic signal of a 1/4 kt explosion at the Soviet test site clearly recorded from a seismic array 3,800 kilometers away in Norway.

One must presume, however, that a country attempting to test clandestinely would use every means to reduce the size of the seismic signal created by the explosion and fool the monitoring network. For example, a particularly challenging evasion scenario would be the case of muffling a small clandestine nuclear test explosion by setting it off in a large underground cavity, and masking the muffled signals with a large chemical explosion that is simultaneously set off under the guise of legitimate industrial activity.

Obviously a seismic network must not only be able to detect and identify explosions under ideal circumstances, it must also demonstrate that it is capable of detecting and identifying seismic events with confidence despite any credible evasion scenario. As the size of the explosion to be monitored becomes smaller, this task becomes increasingly difficult for several reasons:

(1) there are more opportunities for evading the monitoring network,

(2) there are more earthquakes and industrial explosions from which small clandestine explosions need to be distinguished, and

(3) there are more factors that can strongly influence the seismic signal.

Seismic monitoring is limited not by its inherent sensitivity, but rather by the ability to demonstrate that a clandestine test would be distinguishable from large numbers of small earthquakes and large chemical explosions. Ultimately, there will always be a limit to the capability of any given monitoring network, and hence there will always be a threshold below which the uncertainty of any monitoring system will increase. As Dr. Sharfman mentioned as part of our general conclusions, determining the level below which a treaty cannot be adequately verified is a political judgement of the point at which the risks of a treaty outweigh its benefits.

Given all of this, most experts believe that a high-quality, well run network of internal stations could monitor a threshold of around 5 kt. Expert opinion ranges from 1 kt to 10 kt; the differences stem from differing judgements about what technical provisions can be negotiated (for example: how extensive a seismic network can be installed within each country, what inspection provisions can be made for chemical explosions, how many calibration shots are needed, etc.), how much the use of high frequency seismic signals will improve our capability, and what levels of monitoring capability are necessary to give us confidence that the Soviet Union would not risk testing above the threshold.

The range of uncertainty in estimating monitoring capability exists because we are extrapolating the performance of a hypothetical seismic network in areas where we have only limited data and experience. Because the range of uncertainty will be narrowed only by more data and experience from within the Soviet Union, a phased approach makes sense. For example, one could begin with a limit of, say, 10 kilotons that can be monitored with high confidence, but establish the monitoring provisions for an even lower level. As information, experience, and confidence increase, the threshold could be subsequently lowered.

How about lower yields or a complete ban? Such treaties could still be considered to be in the national interest if, taking both seismic and nonseismic verification methods into account, the significance of undetected violations (if they were to occur) would be outweighed by the benefits of such a treaty.

QUOTAS

Another proposal that has received attention is the establishment of a quota, or a numerical limit on the number of tests that each side could conduct in a year. Could such quotas be verified with seismic methods?

The same arguments regarding a lower threshhold can be applied here. Above a threshhold of roughly 1 kiloton, seismic methods can detect, identify, and count all nuclear explosions unless elaborate arrangements are made to conceal them. Above the range of 1-10 kilotons, even elaborate clandestine explosions cease to be feasible.

This suggests that a quota could be expressed in terms of a numerical limitation on explosions within a given yield range -- such as 5 kilotons to 150 kilotons, 1 kiloton to 50 kilotons, etc. Explosions larger than the top of the range would be prohibited; explosions smaller than the bottom of this range could be carried out without restriction. In this case, we could have high confidence in verifying compliance with the numerical limit, because it would be highly expensive, difficult, and risky to carry out a clandestine test with any hope of not being caught. If a given test were important enough to justify such an effort, it would be important enough to be included in the quota in the first place.

Mr. Chairman, in conclusion I would just like to state that small differences of opinion concerning monitoring capability will always remain because parts of the debate are comparable to discussions of "half-full" versus "half-empty" glasses of water. Some will review the complex process of seismic monitoring and will conclude that a country could cheat if there is any uncertainty in any step in the process. Others will put the burden of certainty on the complicated evasion scenarios and conclude that when considering all means of intelligence evasion is too difficult and risky to be credible. The OTA report presents the range of opinion where technical

consensus lies. Monitoring should be approached through a combination of seismic methods, treaty constraints, and inspections to provide the levels of verification desired. If such a combination approach is taken and appropriate supplementary provisions are negotiated within the treaty, seismology can be very effective and low yields can be monitored with high confidence.

These are our major findings. Dr. Sharfman and I would be happy to answer any of your questions.

Excerpt from Seismic Verification of Nuclear Testing Treaties
Office of Technology Assessment, May 1988

Executive Summary

Technologies that were originally developed to study earthquakes may now enable the United States to verify a treaty with the Soviet Union to further limit the testing of nuclear weapons.

INTRODUCTION

Seismology now provides a means to monitor underground nuclear explosions down to low yields, even when strenuous attempts are made to evade the monitoring system. By doing so, seismology plays a central role in verifying arms control agreements that limit the testing of nuclear weapons. Seismology, however, is like any other technology: it has both strengths and limitations. If the capabilities of seismic monitoring are to be fully realized, it is necessary to understand both how the strengths can be used and how the limitations can be avoided.

To a great extent, the capabilities of any given seismic monitoring network are determined by how the monitoring task is approached and what supplementary provisions are negotiated within the treaty. If agreements can be negotiated to reduce uncertainty, then seismology can be very effective and extremely low yields could be monitored with high confidence.

This report addresses two key questions:

1. down to what size explosion can underground testing be seismically monitored with high confidence, and
2. how accurately can the yields of underground explosions be measured seismically?

The answers to these questions provide the technical information that lies at the heart of the political debate over:

1. how low a threshold test ban treaty with the Soviet Union we could verify,
2. whether the 1976 Threshold Test Ban Treaty is verifiable, and
3. whether the Soviet Union has complied with present testing restrictions.

Seismic monitoring as discussed in this study is evaluated without specific references to the particular treaty regime to which it is to apply. There will always be some limit to the capability of any given monitoring network, and hence there will always be a threshold below which a seismic network could not monitor with high confidence. Consequently, should a total test ban be enacted there will be a very low threshold below which seismic methods cannot provide high confidence monitoring. Such a treaty could still be considered to be in the national interest if, taking both seismic and nonseismic verification methods into account, the significance of undetected violations (if they were to occur) would be outweighed by the benefits of such a treaty.

THE TEST BAN DEBATE

Test ban treaties are a seemingly simple approach to nuclear arms control, yet their impact is complex and multi-faceted. The decision as to whether a given test ban treaty is in our overall national interest is dependent on many questions concerning its effects. Disadvantages in one area must be weighed against advantages in another. Consequently, all aspects of a new treaty must be considered together and the cumulative impact evaluated in terms of a balance with the Soviet Union. Finally, the total net assessment of the effects of a

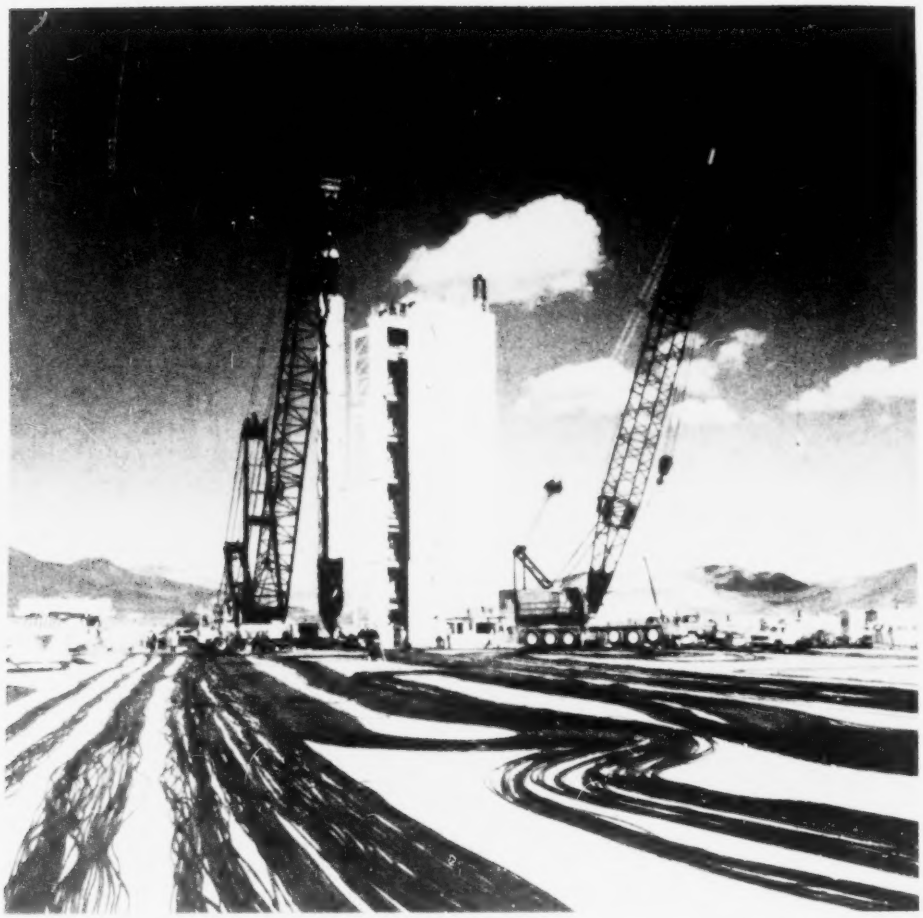


Photo credit: Department of Energy

Signal cables and test device being lowered down test hole

treaty on our national security must be weighed against the alternative: no treaty.

One's opinion about the effects of a test ban, and thus its desirability, is largely dependent on one's philosophical position about the role of a nuclear deterrent and the extent to which arms control can contribute to national security. It is perhaps because test ban treaties go to the very heart of nuclear weapons policy that the debate over them remains unresolved. Three decades of negotiation between the United

States and the U.S.S.R. have produced only three limitation treaties, two of which remain unratified:

1. **1963 Limited Nuclear Test Ban Treaty (LTBT).** This treaty bans nuclear explosions in the atmosphere, in outer space, and under water. It was signed by the United States and the U.S.S.R. on August 5, 1963 and has been in effect since October 10, 1963. Over 100 other countries have also signed this treaty.
2. **1974 Threshold Test Ban Treaty (TTBT).** This treaty restricts the testing of underground nuclear weapons to yields no greater than 150 kilotons (kt). It was signed by the United States and the U.S.S.R. on July 3, 1974. Although the TTBT has yet to receive the consent of the U.S. Senate, both nations consider themselves obligated to adhere to it.
3. **1976 Peaceful Nuclear Explosions Treaty (PNET).** This treaty is a complement to the TTBT and restricts individual peaceful nuclear explosions (PNEs) to yields no greater than 150 kt, and aggregate yields in a salvo to no greater than 1500 kt. It was signed by the United States and the U.S.S.R. on May 28, 1976. Although PNET has yet to receive the consent of the U.S. Senate, both nations consider themselves obligated to adhere to it.

Nuclear explosions compliant with these treaties can only be conducted by the United and the U.S.S.R. underground, at specific test sites (unless a PNE), and with yields no greater than 150 kt. Although they have had important positive environmental and arms control impacts, these treaties have not prevented the development of new types of warheads and bombs. For this reason, public interest in a complete test ban or a much lower threshold remains strong, and each year a number of proposals continue to be brought before the Congress to limit further the testing of nuclear weapons.

THE MEANING OF VERIFICATION

For the United States, the main national security benefits derived from test limitation treaties are a result of the Soviet Union being similarly restricted. In considering agreements that bear on such vital matters as nuclear weapons development, each country usually assumes as a cautious working hypothesis that the other parties would cheat if they were sufficiently confident that they would not be caught. Verification—the process of confirming compliance and detecting violations if they occur—is therefore central to the value of any such treaty.

"To verify" means to establish truth or accuracy. Yet in the arena of arms control, the process of verification is political as well as technical. It is political because the degree of verification needed is based upon one's perception of the benefits of a treaty compared with one's perception of its disadvantages and the likelihood of violations. No treaty can be considered to be either verifiable or unverifiable without such a value judgment. Moreover, this judgment is complex because it requires not only an understanding of the capabilities of the monitoring systems, but also an assessment as to what is an acceptable level of risk, and a decision as to what should constitute significant noncompliance. Consequently, people with differing perspectives on the role of nuclear weapons in national security and on the motivations of Soviet leadership will differ on the level of verification required.[1]

[1]This issue is discussed further in chapter 2, *Seismic Verification in the Context of National Security*.

ASPECTS OF MONITORING UNDERGROUND NUCLEAR EXPLOSIONS

Like earthquakes, the force of an underground nuclear explosion creates seismic waves that travel through the Earth. A seismic monitoring network must be able both to *detect* and to *identify* seismic signals. *Detection* consists of recognizing that a seismic event has occurred and locating the source of the seismic signals. *Identification* involves determining whether the source was a nuclear explosion. In the case of a threshold treaty, the monitoring network must also be able to *estimate the yield* of the explosion from the seismic signal to determine if it is within the limit of the treaty. All of this must be done with a capability that can be demonstrated to adequately defeat any credible attempt to *evade* the monitoring network.

If the seismic signals from explosions are not deliberately obscured or reduced by special efforts, seismic networks would be capable of *detecting* and *identifying* with confidence nuclear explosions with yields below 1 kt. What stops this capability from being directly translated into a monitoring threshold is the requirement that the monitoring network be able to accomplish detection and identification with high confidence in spite of any credible evasion scenario for concealing or reducing the seismic signal from a test explosion.

Demonstrating that the monitoring capability meets this requirement becomes complex at lower yields. As the size of the explosion becomes smaller:

- there are more opportunities for evading the monitoring network,
- there are more earthquakes and industrial explosions from which such small clandestine explosions need to be distinguished, and
- there are more factors that can strongly influence the seismic signal.

The cumulative effect is that the lower the yield, the more difficult the task of monitoring against possible evasion scenarios.

The threat of evasion can be greatly reduced by negotiating within a treaty various cooperative monitoring arrangements and testing restrictions. However, there will eventually be a yield below which the uncertainty of any monitoring regime will increase significantly. **The point at which the uncertainties of the monitoring system no longer permit adequate verification is a political judgment of the point at which the risks of the treaty outweigh the benefits.**

Determining the credibility of various evasion methods requires subjective judgments about levels of motivation and risk as well as more objective technical assessments of the capability of the monitoring system. To separate the technical capabilities from the subjective judgments, we will first describe our capability to detect and identify seismic events and then will show how this capability is limited by various possible evasion methods. All considerations are then combined to address the summary question: *How low can we go?*

Detecting Seismic Events

The first requirement of a seismic network is that it be capable of detecting a seismic event. If the Earth were perfectly quiet, this would be easy. Modern seismometers are highly sophisticated and can detect remarkably small motions. Limitations are due not to the inherent sensitivity of the instrument but rather to phenomena such as wind, ocean waves, and even rush hour traffic. All of these processes cause ground vibrations that are sensed by seismometers and recorded as small-scale background motion, collectively referred to as "noise." Seismic networks, consisting of groups of instruments, are designed to distinguish events like earthquakes and explosions from this ever-present background noise. The extent to which a seismic network is capable of detecting such events is dependent on many factors. Of particular importance are the types of seismic stations used, the number and distribution of the stations, the amount of back-

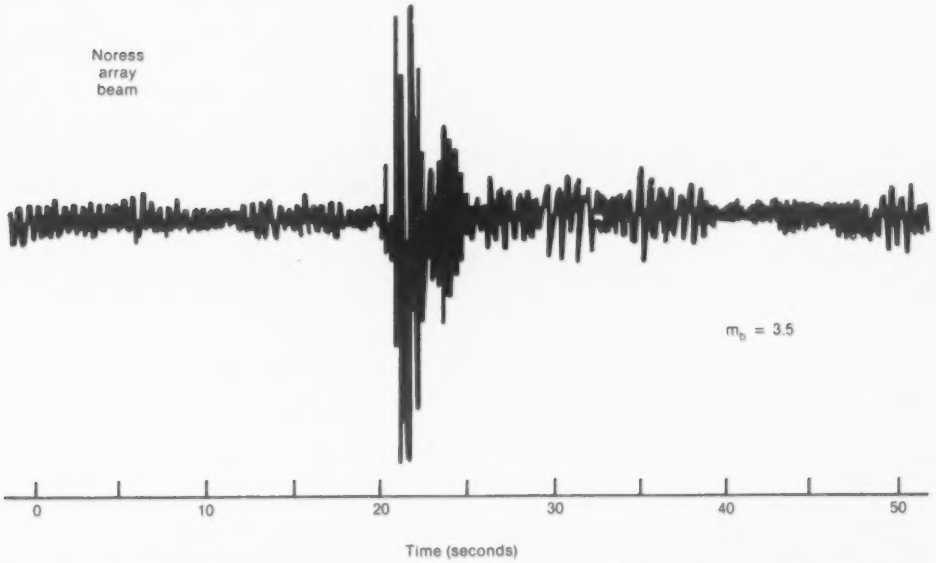
ground noise at the site locations, and the efficiency with which seismic waves travel from the source to the receiving station through the surrounding geologic area.

Detecting seismic events can be accomplished with high certainty down to extremely small yields. A hypothetical seismic network with stations only *outside* the Soviet Union would be capable of detecting well-coupled[1] explosions with yields below 1 kt anywhere within the Soviet Union and would be able to detect even smaller events in selected regions. The existing seismic array in Norway, for example, has easily detected Soviet explosions with yields of a fraction of a kt conducted 3,800 kilometers away at the Soviet test site in Eastern Kazakhstan (figure 1-1).

Seismic stations within the Soviet Union would further improve the detection capability of a network. In principle, almost any desired signal *detection* level could be achieved within the Soviet Union if a sufficient number of internal stations were deployed. In this sense, the detection of seismic events does not provide a barrier for monitoring even the lowest threshold treaties. From a monitoring stand-

[1]A "well-coupled" explosion is one where the energy is well transmitted from the explosion to the surrounding rock.

Figure 1-1.—Signal From Semipalatinsk



Seismic signal from a 0.25 kt explosion at the Soviet test site near Semipalatinsk. Recorded 3,800 km away at the NORESS seismic array in Norway on July 11, 1985. The signal to noise ratio is about 30 indicating that much smaller explosions could be detected even at this great distance.

SOURCE: R.W. Alewine III, "Seismic Sensing of Soviet Tests," *Defense 85*, December 1985, pp. 11-21.

point, stations within the Soviet Union are more important for improving *identification* capabilities than for further reduction of the already low detection threshold.

Identifying Seismic Events as Nuclear Explosions

Once a seismic signal has been detected, the next task is to determine whether it was created by a nuclear explosion. Seismic signals are generated not only by nuclear explosions, but also by natural earthquakes, rockbursts in mines, and chemical explosions conducted for mining, quarry blasting, and construction.

Every day there are many earthquakes around the globe whose seismic signals are the same size as those of potential underground nuclear explosions. Several methods can be applied to differentiate earthquakes from underground nuclear explosions. Note, however, that no one method is completely reliable. It is the set of different identification methods taken as a whole and applied in a systematic fashion that is assessed when summaries on capability are given. In this sense, identification is a "winnowing" process.

The most basic method of identification is to use the location and the depth of the event. Over 90 percent of all seismic events in the U.S.S.R. can be classified as earthquakes simply because they are either too deep or not in a plausible location for a nuclear explosion. For seismic events that are in a location and at a

Photo credit: Department of Energy

Craters formed by cavity collapse in Yucca Flat, Nevada Test Site.

depth that could be an explosion, other methods of discrimination based on physical differences between earthquakes and explosions are used.

When a nuclear device explodes underground, it applies uniform pressure to the walls of the cavity it creates. As a result, explosions are seen seismically as highly concentrated sources of *compressional waves*, sent out with approximately the same strength in all directions from the point of the detonated device. An earthquake, on the other hand, occurs when two blocks of the Earth's crust slip past each other along a fault. An earthquake generates *shear waves* from all parts of the fault that rupture.

These fundamental differences between earthquakes and explosions are often exhibited in their seismic signals. As a result, seismologists have been able to develop a series of methods to differentiate the two sources based on the different types of seismic waves they create. The combination of all methods, when applied in a comprehensive approach, can differentiate with high confidence between explosions, down to low yields, and earthquakes.

As the size of the seismic events gets smaller, nuclear explosions must be distinguished not only from earthquakes, but also from other kinds of explosions. Industrial chemical explosions (e.g. in a quarry operation) pose a particularly difficult problem because their seismic signals have physical characteristics similar to those of nuclear explosions. Consequently, the seismic methods that are routinely used to differentiate earthquakes from explosions cannot distinguish between some legitimate chemical explosions for mining purposes and a clandestine nuclear test explosion. Fortunately, industrial explosions in the range of 1 to 10 kt are rare (less than one a year). Large explosions are usually ripple fired so as to minimize ground vibration and fracture rock more efficiently. Ripple firing is often accomplished with bursts spaced about 0.2 seconds apart over a duration of about a second. Recent work suggests that this ripple firing has an identifiable signature apparent in the observed seismic signals, and therefore can be used to identify such chemical explosions. However, the absence of evidence for ripple firing cannot be taken as evidence that the event is not a chemical explosion. Because of the size consideration, industrial explosions are not an identification problem for normal nuclear explosions above 1 kt. The difficulty, as we will see later, comes in distinguishing between a small *decoupled* nuclear test and a large salvo-fired chemical explosion. This difficulty can be limited through such treaty provisions as options for inspections and constraints on chemical explosions.[3]

Because a seismic signal must be clearly detected before it can be identified, the threshold for identification will always be greater than the threshold for detection. As described in the previous section, however, the detection threshold is quite low. Correspondingly, even a hypothetical network consisting of stations only *outside* the Soviet Union would be capable of *identifying* seismic events with magnitudes corresponding to about 1 kt *if* no attempts were made to evade the monitoring system.[4] Seismic stations within the Soviet Union would further improve the identification capability of a network.

It has been argued that the use of high frequency seismic data will greatly improve our capability to detect and identify low-yield nuclear explosions.[5,6] Recent experiments conducted by the Natural Resources Defense Council together with the Soviet Academy of Sciences are beginning to provide high frequency seismic data from within the Soviet Union that shows clear recordings of small explosions (see box 1-A). There remains, however, a lack of consensus on the extent to which the use of higher frequency data will actually im-

[3] See chapter 6, *Evading a Monitoring Network*, for a discussion of treaty constraints.

[4] See chapter 5, *Identifying Seismic Events*.

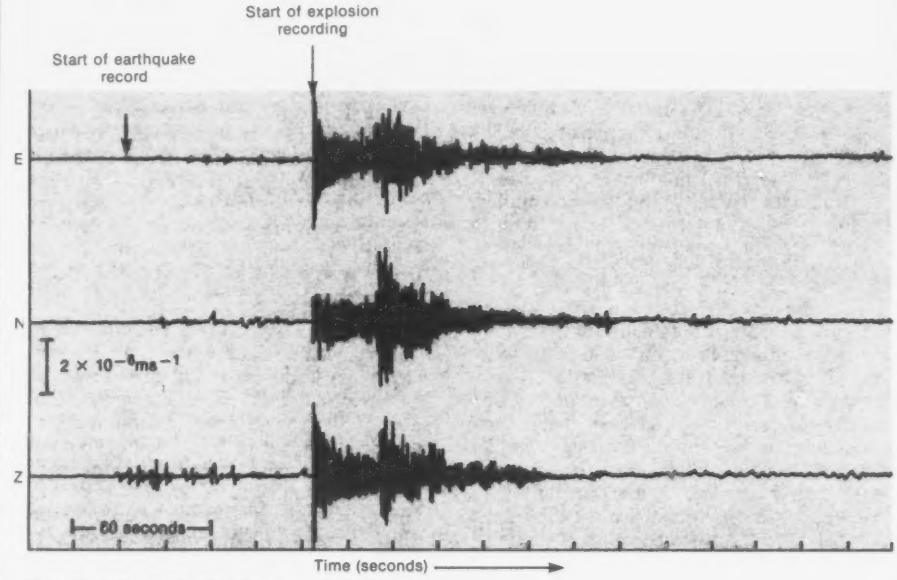
[5] For example, much lower identification thresholds have been defended by J.F. Evernden, C.B. Archambeau, and E. Cranswick, "An Evaluation of Seismic Decoupling and Underground Nuclear Test Monitoring Using High-Frequency Seismic Data," *Reviews of Geophysics*, vol. 24, May 1986, pp. 143-215.

[6] See chapter 4, *Detecting Seismic Events*, and chapter 5 *Identifying Seismic Events*, for discussions of high frequency monitoring.

Box 1-A.—NRDC/Soviet Academy of Sciences

New seismic data from the Soviet Union is becoming available through an agreement between the Natural Resources Defense Council and the Soviet Academy of Sciences. The agreement provides for the establishment of a few high-quality seismic stations within the Soviet Union around the area of the Soviet test site in Kazakhstan. The agreement also included experiments in which the Soviet Union detonated chemical explosions of known yield near the test site so that the test site could be calibrated.

The seismograph below is from a 0.01 kt chemical explosion detonated near the Soviet test site and recorded 255 km away. The signal of the explosion can be clearly seen along with the coincidental arrival of seismic waves caused by a large earthquake that occurred south of New Zealand. The three components of ground motion are east-west (E), north-south (N), and vertical (Z).



SOURCE: Natural Resources Defense Council.

prove monitoring capabilities. The lack of consensus is due to differences in opinion as to how well U.S. experience and the limited experience near the Soviet test site can be extrapolated to an actual comprehensive monitoring system throughout the Soviet Union. Consequently, the debate over improved capability will probably remain unresolved until more extensive data can be collected at regional distances from areas throughout the Soviet Union. Nevertheless, there is general agreement among seismologists that good data is obtainable at higher frequencies than those used routinely today, and that this data offers advantages for nuclear monitoring that should continue to be explored.

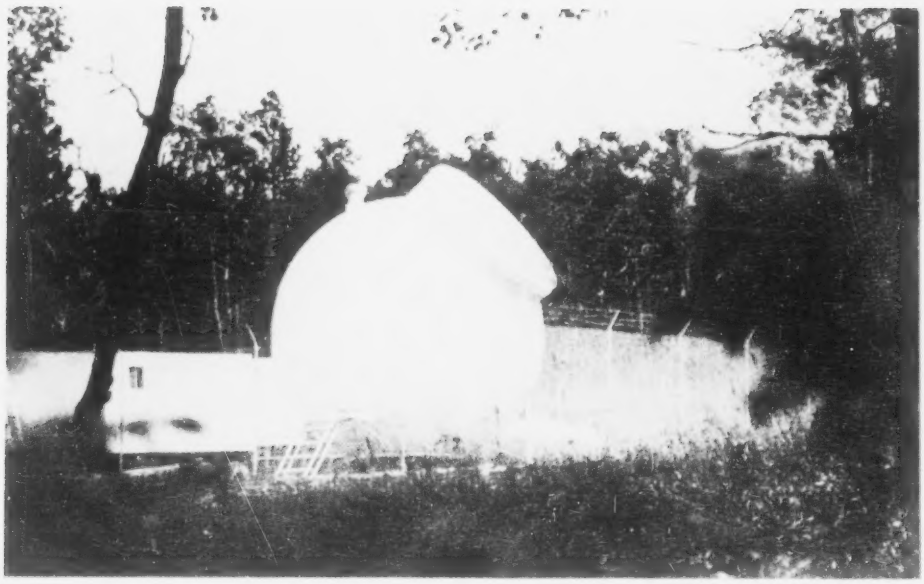


Photo credit: Sandia National Laboratories

An example of what an internal seismic station might look like.

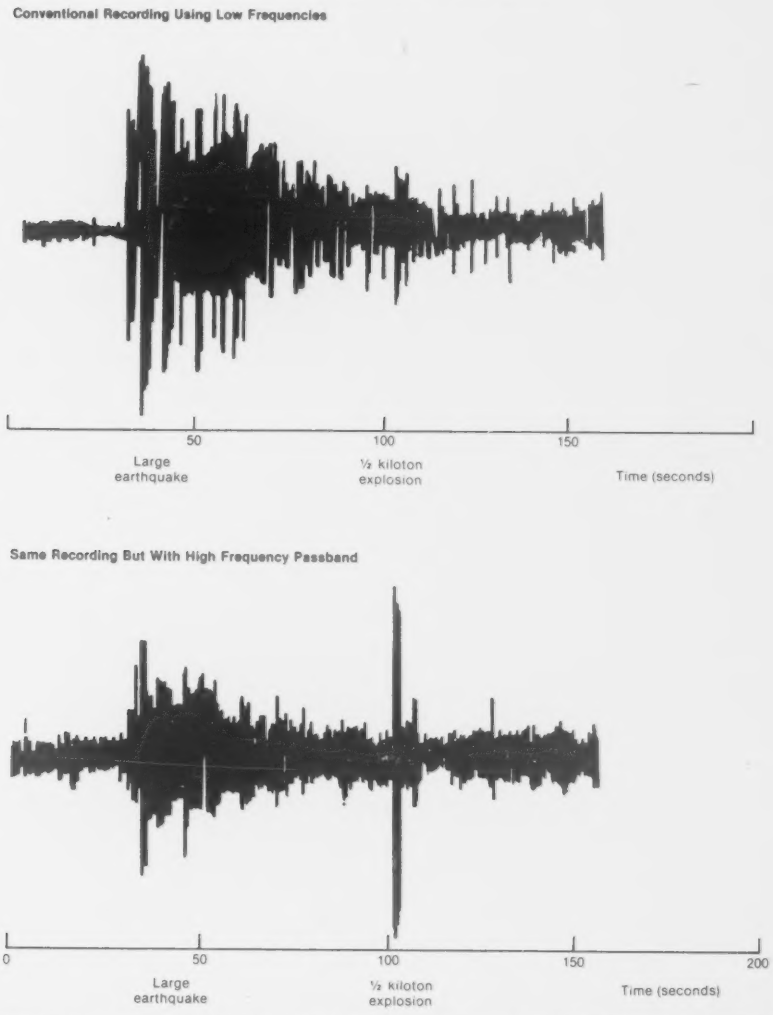
Evading a Seismic Monitoring Network

To monitor a treaty, nuclear tests must be detected and identified with high confidence even if attempts are made to evade the monitoring system. As mentioned earlier, it is the feasibility of various evasion scenarios that sets the lower limit on the monitoring capability. The major evasion concerns are:

- that the signal of an explosion could be hidden in the signal of a naturally occurring earthquake,
- that an explosion could be muffled by detonating it in a large underground cavity, or
- that a nuclear test could be disguised as or masked by a large legitimate industrial explosion.

The hide-in-earthquake scenario assumes that a small nuclear test could be conducted by detonating the explosion during or soon after an earthquake. If the earthquake were sufficiently large and the small explosion properly timed, the seismic signal of the explosion would be hidden in the seismic signal of the earthquake. However, it is not practical for an evader to wait for an earthquake that is in the immediate vicinity of the test site. Therefore, the masking earthquake would have to be large and at some distance. The smaller nuclear explosion will produce higher frequency signals than the earthquake, and filtering the signals will reveal the signals from the explosion (figure 1-2). For this and other reasons (chapter 6), the hide-in-earthquake scenario need no longer be viewed as a credible evasion threat for explosions above 5-10 kt. To counter this threat for explosions below 5-10 kt may require access to data from seismic stations within the Soviet Union, because the higher frequency seismic signals from explosions below 5-10 kt

Figure 1-2.—Explosion and Earthquake



Both the upper and lower seismograms were recorded in Norway and cover the same period of time. The upper seismogram is the conventional recording of low-frequency seismic waves. Both it and the lower recording show, at the time of 30 seconds, the arrival of waves from a large earthquake that occurred in the eastern part of the Soviet Union. About one minute after the earthquake, at a time of 100 seconds, the Soviet Union conducted a very small (about ½ kt) underground nuclear explosion at their Kazakhstan test site. With the standard filter (upper seismogram), the signal of the explosion appears hidden by the earthquake. Using a passband filter for higher frequency seismic waves (lower seismogram), the explosion is revealed.

SOURCE: Semiannual Technical Summary for Norwegian Seismic Array for 1984, Royal Norwegian Council for Scientific and Industrial Research, Scientific Report No. 1-84/85.

may not always be picked up by stations outside the Soviet Union.

Decoupling appears to be potentially the most effective of all evasion methods. It involves detonating a nuclear device in a large underground cavity so as to muffle the seismic signal. If the explosion occurs in a large cavity, the explosive stresses are reduced because they are spread over the large area of the cavity wall. At a certain cavity size, the stresses will not exceed the elastic limit of the rock. At such a point, the explosion is said to be "fully decoupled" and the seismic signal becomes greatly reduced. At low seismic frequencies, a fully decoupled explosion may have a signal 70 times smaller than that of a fully coupled explosion. At high frequencies the decoupling factor is probably reduced to somewhere between 10 and 7.

Above 10 kt, decoupling is not considered to be a credible evasion scenario because: 1) the clandestine construction of a cavity large and strong enough to decouple a 10 kt explosion is not feasible; and 2) even if such an explosion were somehow fully decoupled, the seismic signal would stand a good chance of being detected and possibly identified. Therefore, decoupling could be most effective for small explosions up to a few kt, particularly when done in conjunction with a legitimate industrial explosion. For example, a potential evasion method would be to secretly decouple a small nuclear explosion in a large underground cavity and mask or attribute the muffled signals to a large chemical explosion that is simultaneously detonated under the guise of legitimate industrial activity.

As discussed in the section on identification, differentiating a small nuclear explosion from a legitimate industrial explosion associated with mining and quarry blasting is difficult because both produce similar seismic signals. This is not a problem for identification under normal circumstances because industrial explosions in the 1-10 kt range occur less than once a year. However, industrial explosions may create a problem when considering the decoupling evasion scenario. That is, some low-yield decoupled explosions might produce seismic signals comparable to those observed from large chemical explosions and no routine capability has yet been developed to differentiate, with high confidence, between such signals.

None of the evasion scenarios poses any serious problem for monitoring explosions above 10 kt. However, to provide adequate monitoring capability below 10 kt, efforts must be made to limit decoupling opportunities. This would include an internal seismic network and provisions within the treaty (such as pre-notification with the option for on-site inspection) to handle the large numbers of chemical explosions. At a few kt, decoupling becomes possible when considered as part of an evasion scenario. Arranging such a test, however, would be both difficult and expensive; and it is not clear that the evader could have confidence that such a test (even if it were successful) would go undiscovered. However, the possibility remains that a few tests of small magnitude could be conducted and remain unidentified as nuclear explosions.

HOW LOW CAN WE GO?

Given all the strengths and limitations of seismic methods in detecting and identifying Soviet nuclear explosions, combined with the credibility of the various evasion scenarios, the ultimate question of interest for monitoring any low-yield threshold test ban treaty is essentially: *How low can we go?* The answer to that question depends largely on what is negotiated in the treaty. As we have seen, the challenge for a monitoring network is to demonstrate a capability to distinguish credible evasion attempts from the background of frequent earthquakes and legitimate industrial explosions that occur at low yields.

The monitoring burden placed on the seismic network by various evasion scenarios can be greatly lessened if seismology gets some help. The sources of help are varied and numerous: they include not only seismic monitoring but also other methods such as satellite surveillance, radioactive air sampling, communication intercepts, reports from intelligence agents, information leaks, interviews with defectors and emigrés, on-site inspections, etc. **The structure of any treaty or agreement should be approached through a combination of seismic methods, treaty constraints, and inspections that will reduce the uncertainties and difficulties of applying seismic monitoring methods to every conceivable test situation.** Yet with these considerations in mind, some generalizations can still be made about monitoring at various levels.

Level 1—Above 10 kt

Nuclear tests with explosive yields above 10 kt can be readily monitored with high confidence.[7] This can be done with external seismic networks and other national technical means. The seismic signals produced by explosions of this size are discernible and no method of evading a seismic monitoring network is credible. However, for accurate monitoring of a 10 kt threshold treaty it would be desirable to have stations within the Soviet Union for improved yield estimation, plus treaty restrictions for handling the identification of large chemical explosions in areas where decoupling could take place.

Level 2—Below 10 kt but Above 1-2 kt

Below 10 kt and above 1-2 kt, the monitoring network must demonstrate a capability to defeat evasion scenarios. Constructing an underground cavity of sufficient size to fully decouple an explosion in this range is believed to be feasible in salt, with dedicated effort and resources. Consequently, the signals from explosions below 10 kt could perhaps be muffled. The seismic signals from these small muffled explosions would need not only to be detected, but also distinguished from legitimate chemical industrial explosions and small earthquakes. Demonstrating a capability to defeat credible evasion attempts would require seismic stations throughout the Soviet Union (especially in areas of salt deposits), negotiated provisions within the treaty to handle chemical explosions, and stringent testing restrictions to limit decoupling opportunities. If such restrictions could be negotiated, most experts believe that a high-quality, well run network of internal stations could monitor a threshold of around 5 kt. Expert opinion about the lowest yields that could reliably be monitored ranges from 1 kt to 10 kt; these differences of opinion stem from differing judgments about what technical provisions can be negotiated into the treaty, how much the use of high frequencies will improve our capability, and what levels of monitoring capability are necessary to give us confidence that the Soviet Union would not risk testing above the threshold.

Level 3—Below 1-2 kt

For treaty thresholds below 1 or 2 kt, the burden on the monitoring country would be much greater. It would become possible to decouple illegal explosions not only in salt domes but also in media such as granite, alluvium, and layered salt deposits. Although it may prove possible to detect such explosions with an extensive internal network, there is no convincing evidence that such events could be confidently identified with current technology. That is, additional work in identification capability will be required before it can be determined whether such small decoupled explosions could be reliably differentiated from the background of many small earthquakes and routine chemical explosions of comparable magnitude.

Level 4—Comprehensive Test Ban

There will always be some threshold below which seismic monitoring cannot be accom-

[7] The United States and the Soviet Union presently restrict their testing to explosions with yields no greater than 150 kt. The bomb dropped on Hiroshima was estimated to have a yield of 13 kt.

plished with high certainty. A comprehensive test ban treaty could, however, still be considered adequately verifiable if it were determined that the advantages of such a treaty would outweigh the significance of any undetected clandestine testing (should it occur) below the monitoring threshold.

ESTIMATING THE YIELD OF NUCLEAR EXPLOSIONS

For treaties that limit the testing of nuclear weapons below a specific threshold, the monitoring network not only must detect and identify a seismic event such as a nuclear explosion but also must measure the yield to determine whether it is below the threshold permitted by the treaty. This is presently of great interest with regard to our ability to verify compliance with the 150-kt limit of the 1974 Threshold Test Ban Treaty.

The yield of a nuclear explosion may be estimated from the seismic signal it produces. Yield estimation is accomplished by measuring from the seismogram the size of an identified seismic wave. When corrected for distance and local effects at the recording station, this measurement is referred to as the seismic magnitude. The relationship between seismic magnitude and explosive yield has been determined using explosions of known yields. This relationship is applied to estimate the size of unknown explosions. The problem is that the relationship was originally determined from U.S. and French testing and calibrated for the Nevada test site. As a result, Soviet tests are measured as if they had been conducted at the Nevada test site unless a correction is made. No correction would be needed if the U.S. and Soviet test sites were geologically identical, but they are not.

The Nevada test site, in the western United States, is in a geologically young and active area that is being deformed by the motion between the North American and Pacific tectonic plates. This recent geologic activity has created an area of anomalously hot and possibly even partially molten rock beneath the Nevada test site. As a result, when an explosion occurs at the Nevada test site, the rock deep beneath Nevada absorbs a large proportion of the seismic energy. The Soviet test site, on the other hand, is more similar to the geology found in the eastern United States. It is a geologically old and stable area, away from any recent plate tectonic activity. When an explosion occurs at the Soviet test site, the cold, solid rock transmits the seismic energy strongly. As a consequence, waves traveling from the main Soviet test site in Eastern Kazakhastan appear much larger than waves traveling from the Nevada test site. Unless that difference is taken into account, the size of Soviet explosions will be greatly overestimated.

The geological difference between the test sites can result in *systematic error*, or "*bias*," in the way that measurements of seismic waves are converted to yield estimates. *Random error* is also introduced into the estimates by the measurement process. Thus, as with any measurement, there is an overall uncertainty associated with determining the size of an underground nuclear explosion. This is true whether the measurement is being made using seismology, hydrodynamic methods, or radiochemical methods. It is a characteristic of the measurement. To represent the uncertainty, measurements are presented by giving the most likely number (the mean value of all measurements) and a range that represents both the random scatter of the measurement and an estimate of the systematic uncertainty in the interpretation of the measurements. It is most likely that the actual value is near the central number and it is increasingly unlikely that the actual number would be found towards either end of the scatter range. When appropriate, the uncertainty range can be expressed by using what is called a "factor of uncertainty." For example, a factor of 2 uncertainty means that the best estimate of the yield (the "measured central value") when multiplied or divided by 2, defines a range within which the true yield will fall in 95 out of 100 cases. This is the high de-

gree of certainty conventionally used in seismology and may or may not be appropriate in a verification context.[8]

The uncertainty associated with estimates of the systematic error can be greatly reduced by negotiating provisions that restrict testing to specific test sites and by calibrating the test sites. If such calibration were to be an integral part of any future treaty, the concern over systematic errors of this kind would become minimal. The majority of errors that would remain would be random. As discussed in chapter 2, a country considering cheating could not take advantage of the random error, because it would not be possible to predict how the random error would act on any given evasion attempt. In other words, if a country attempted to test above the threshold, it would have to realize that with every test the chances of appearing in compliance would decrease and at the same time the chance that at least one of the tests would appear in unambiguous violation would increase. For this reason, the range of uncertainty should not be considered as a range within which cheating could occur.

Most of the systematic error associated with estimating the yields of Soviet nuclear explosions is due to geological differences between the U.S. and Soviet test sites and in the coupling of the explosion to the Earth. Therefore, the single most important thing that can be done to reduce the uncertainty in yield estimation is to calibrate the test sites. Calibration could be accomplished through an exchange of devices of known yield, or through independent measures of the explosive yield such as can be provided by radiochemical or hydrodynamic methods (See box 1-B).

Our present capability to estimate seismically the yields of Soviet explosions is often cited as a factor of two.[9] While this may reflect present operational methods, it is not an accurate representation of our capability. Our capability could be greatly improved by incorporating new methods of yield estimation. Most seismologists feel that if new methods were applied, the resulting uncertainty for measuring explosive yields in the range of 150 kt at the Soviet test site would be closer to a factor of 1.5 than a factor of two.[10] Present methods are stated to be accurate only to a factor of two in part because they have not yet incorporated the newer methods of yield estimation that use surface waves and Lg waves.[11] The uncertainty of this comprehensive approach could be further reduced if calibration shots were performed and testing were restricted to areas of known geologic composition. **It is estimated that through such measures, the uncertainty in seismically measuring Soviet tests could be reduced to a level comparable to the uncertainty in seismically measuring U.S. tests. An uncertainty factor of 1.3 is the current capability that seismic methods are able to achieve for estimating yields at the Nevada test site.**

As with detection and identification, yield estimation becomes more difficult at low yields. Below about 50 kt, high-quality Lg-wave signals can only be reliably picked up by stations within the Soviet Union less than 2,000 km from the test site. For explosions below 10 kt, the uncertainty increases because small explosions do not always transmit their signals efficiently to the surrounding rock. For small explosions, the uncertainty could be reduced by restricting such tests to depths below the water

[8]See chapter 2, *Seismic Verification in the Context of National Security*.

[9]U. S. Department of State, "Verifying Nuclear Testing Limitations: Possible U.S.-Soviet Cooperation, Special Report No. 152," Aug. 14, 1986.

[10]This reduction of uncertainly derives from using more than one statistically independent method. Consider as an example the situation where there are three independent methods of calculating the yield of an explosion, all of which (for the sake of this example) have a factor of two uncertainty in a log normal distribution:

# of Methods	Resulting Uncertainty
1	2.0
2	1.6
3	1.5

By combining methods, the uncertainty can be reduced below the uncertainty of the individual methods. This methodology, however, can only reduce random error. Systematic error, such as differences between the test site, will remain and limit the extent to which the uncertainty can be reduced unless calibration is performed.

[11]See chapter 7, *Estimating the Yields of Nuclear Explosions*.

table, so that their signal will be transmitted effectively.

Our capability to estimate explosive yields would depend to a large degree on the approach that was taken and what was negotiated in future treaties. If new methods of yield determination were incorporated into the measurements and calibration shots were performed, the capability of seismic methods could be improved to a point comparable to the accuracy of other methods, such as CORRTEX, that require a foreign presence and equipment at the test site. In any case, if the objective of reducing the uncertainty is to reduce the opportunities for cheating, small differences in random uncertainty do not matter.

SOVIET COMPLIANCE

The decision as to what constitutes adequate verification should represent a fair assessment of the perceived dangers of non-compliance. This necessarily involves a weighing of the advantages of the treaty against the feasibility, likelihood, and significance of noncompliance. Such decisions are subjective and in the past have been influenced by the desirability of the treaty and the political attractiveness of particular monitoring systems.[12] Specific concern over compliance with test ban treaties has been heightened by findings by the Reagan Administration that:

> "Soviet nuclear testing activities for a number of tests constitute a likely violation of legal obligations under the Threshold Test Ban Treaty."[13]

Although the 1974 Threshold Test Ban Treaty and the 1976 Peaceful Nuclear Explosions Treaty have remained unratified for over 10 years, both nations have expressed their intent to abide by the yield limit. Because neither the United States nor the Soviet Union has indicated an intention *not* to ratify the treaties, both parties are obligated under international law (Article 18, the 1969 Vienna Convention on the Law of Treaties) to refrain from acts that would defeat their objective and purpose.

In examining compliance with the 150-kt threshold, seismic evidence is currently considered the most reliable basis for estimating the yields of Soviet underground nuclear explosions.[14] The distribution of Soviet tests indicates that about 10 (out of over 200) Soviet explosions since the signing of the Threshold Test Ban Treaty in 1974 *could* have estimated yields with central values above the 150 kt threshold limit, depending on how the estimate is made.[15] These 10 tests could actually be at or below the 150 kt limit, but have higher yield estimates due to random fluctuations in the seismic signals. In fact, when the same methods of yield estimation are applied to U.S. tests, approximately the same number of U.S. tests also appear to be above the 150 kt threshold limit. These apparent violations, however, do not mean that one, or the other, or both countries have cheated; nor does it mean per se that seismology is an inadequate method of yield estimation. It is inherent in any method of measurement that if several tests are performed at the limit, some of these tests will have estimated central values above the yield limit. Because of the nature of measurements (using any method), it is expected that about half the Soviet tests at 150 kt would be measured as slightly above 150 kt and the other half would be measured as slightly below 150 kt.

[12] See chapter 2, *Seismic Verification in the Context of National Security*.

[13] "The President's Unclassified Report on Soviet Noncompliance with Arms Control Agreements," transmitted to the Congress, Mar. 10, 1987.

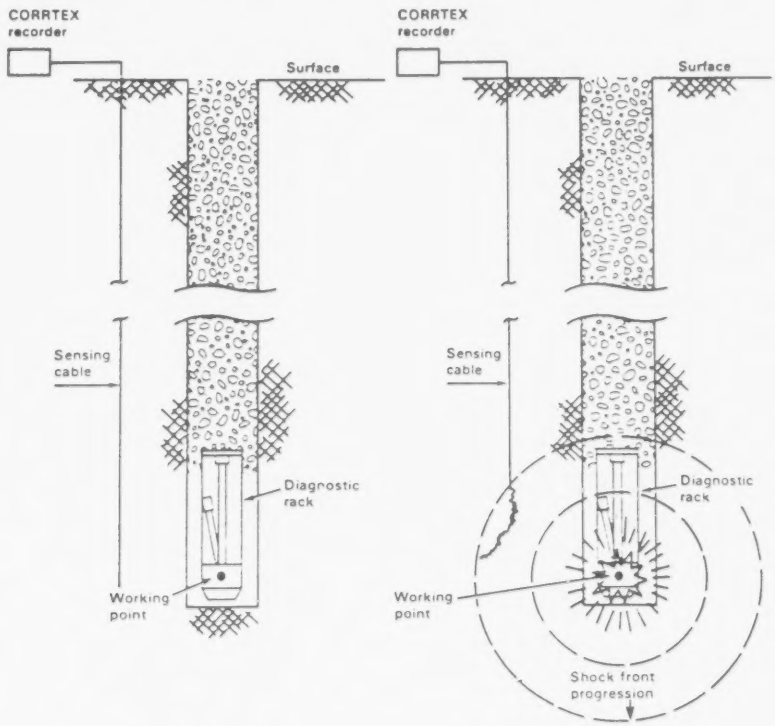
[14] Conclusion of the Defense Intelligence Agency Review Panel as stated in a letter from Roger E. Batzel, Director of Lawrence Livermore National Laboratory to Senator Claiborne Pell on Feb. 23, 1987.

[15] See chapter 7, *Estimating the Yields of Nuclear Explosions*.

Box 1-B.—CORRTEX

CORRTEX (Continuous Reflectometry for Radius versus Time Experiments) is a technique that was developed in the mid-1970s to improve yield estimation using non-seismic (hydrodynamic) methods. In the CORRTEX technique, a satellite hole is drilled parallel to the emplacement hole of the nuclear device and an electrical sensing cable is lowered down the hole (see figure). When the explosion occurs, a shock wave moves outward crushing and electrically shorting the cable.

By measuring with electronic equipment at the surface the rate at which the cable is shorted out, the rate of expansion of the shock wave can be calculated. From the rate of expansion of the shock wave and the properties of the surrounding medium, the yield of the nuclear device can be estimated. A full assessment of this method is presented in the Appendix, *Hydrodynamic Methods of Yield Estimation*.



Typical cable emplacement in satellite hole

Moving shock wave from nuclear detonation crushes and shortens cable

All of the estimates of Soviet and U.S. tests are within the 90 percent confidence level that one would expect if the yields were 150 kt or less. Extensive statistical studies have examined the distribution of estimated yields of explosions at Soviet test sites. **These studies have concluded that the Soviets are observing a yield limit consistent with compliance with the 150 kt limit of the Threshold Test Ban Treaty.**[16] [17]

[16]Ibid.

[17]One of the first groups to carry out such statistical studies was Lawrence Livermore National Laboratory. Their conclusion was reported in open testimony before the Senate Armed Services Committee on Feb. 26, 1987 by Dr. Milo Nordyke, Leader of the Treaty Verification Program.

VERIFICATION OF THE TTBT AND THE PNET

As noted above, the 1974 Threshold Test Ban Treaty and the 1976 Peaceful Nuclear Explosions Treaty have not been ratified. Most recently, the Senate failed to consent to ratification at least in part because of concerns that the size of Soviet explosions cannot be measured with adequate confidence.[18] As a result, for over 10 years the United States has continued to abide by the treaties, yet refused to ratify them, ostensibly because they cannot be adequately verified. Note that if the treaties were ratified, the protocols would come into force calling for an exchange of data which, if validated, would then improve the verification.[19] [20] However, the treaty contains no provisions for an independent verification of the data, most importantly, the yields of the calibration shots. Therefore, many experts question the value of such data, unless the data can be validated.

As a solution to the problem of uncertainty in yield estimation, the administration has recently proposed the use of an on-site measurement system called CORRTEX for all tests above 50 kt. The CORRTEX system is stated to have a factor of 1.3 uncertainty for measuring yields greater than 50 kt at the Soviet test site.[21] [22] The drawbacks are that it requires prenotification and cooperation of the host country to the extent that foreign personnel and their equipment must be allowed at the test site for each test. Also, CORRTEX has limited application for monitoring a low-yield treaty and none for detecting clandestine testing, and so it would not improve our ability to monitor low-yield testing thresholds.

Alternatively, advanced seismic methods could be used. The advantage of seismic methods is that a continued presence of foreign personnel at the test site would not be necessary. Additionally, our ability to monitor all Soviet testing (not just testing above 50 kt) would be improved. **If the Soviet test site was calibrated and advanced seismic methods were utilized, the uncertainty in seismic yield estimation could be reduced to a level comparable to CORRTEX.** In fact, CORRTEX could be used to confirm independently the yields of the calibration shots. The Soviet Union has already agreed to the use of CORRTEX for one or two such explosions at the Soviet test site.[23]

[18]*Threshold Test Ban Treaty and Peaceful Nuclear Explosions Treaty*, Hearings before the Senate Committee on Foreign Relations, Jan. 13 and 15, 1987, S. Hrg. 100-115.

[19]The protocol of the TTBT calls for an exchange of geological data plus two calibration shots from each geophysically distinct testing area.

[20]Monitoring would also be improved by the data that would be obtained from all PNE shots that have occurred in the Soviet Union since 1976.

[21]U. S. Department of State, Bureau of Public Affairs, "U.S. Policy Regarding Limitations on Nuclear Testing, Special Report No. 150," August 1986.

[22]See appendix, *Hydrodynamic Methods of Yield Estimation*.

[23]Statement of the Secretary of State of the United States and Minister of Foreign Affairs of the Soviet Union, Dec. 9, 1987.

A PHASED APPROACH

If the policy decision were made that treaties further restricting or eliminating the testing of nuclear weapons are in our national interest, then from a verification viewpoint there is much to be said for a phased approach to this goal. Conceptually, it would begin with

a limit that can be monitored with high confidence using current methods, but would establish the verification network for the desired lowest level. The threshold would then be lowered as information, experience, and confidence increase.

For example, the United States and the Soviet Union could begin with a treaty that prohibited testing above 10 kt. This is a level that can currently be well monitored seismically.[24] The verification network negotiated within the treaty, however, would be designed with the goal of monitoring down to the 1-2 kt level. This would include a network of advanced seismic stations throughout the Soviet Union to detect off-site testing plus negotiated provisions to reduce evasion possibilities.[25] Principal among these would be to restrict testing to below the water table and to a specified test site where decoupling opportunities would be limited, to require some special handling (such as pre-notification and on-site inspection) for the detonation of large chemical explosions, and to institute measures to confirm a prohibition on decoupling. To reduce the systematic uncertainty in yield estimation, a series of calibration shots would need to be conducted at each test site using either an independent method such as CORRTEX or the exchange of devices of known yield.

After such a network had been in operation for some time, many of the disagreements concerning hypothetical networks would be resolved. It would be known how well seismic waves travel through the geology of the Soviet Union and what noise levels exist in various areas. Through such a process, experience with large-scale monitoring would be gained and there would be more accurate knowledge of what level of monitoring effort is needed. After this information and experience had been obtained, provisions within the treaty could call for the further reduction of the threshold. At that point, it would be better known down to what level monitoring could be accomplished. If it were determined that a lower threshold could be verified, the testing threshold could be set to the new verifiable limit. By the continuation of periodic reviews, the treaty would always be able to use developments in seismology to maximize the restriction of nuclear testing.

This procedure, however, does not take into account any considerations other than seismic verification. It simply presents the maximum restrictions that could be accomplished from a seismic verification standpoint. Considerations other than seismic verification may result in different thresholds being more desirable. Lower thresholds, or even a complete ban on testing, may be chosen if the political advantages are seen to outweigh the risk, and if the significance of minor undetected cheating is seen to be small when all monitoring methods are considered. Higher thresholds may be chosen to permit certain types of testing or to avoid placing a threshold at a boundary where particularly significant tests could occur at yields only slightly above the threshold.

[24] Some experts believe that decoupling is not feasible above 5 kt and consequently, that a 5 kt threshold could be well monitored with existing methods and facilities; while others would place the threshold somewhere between 5 and 10. However, virtually all experts agree that tests above 10 kt can be well monitored, even assuming the monitored country is intent on cheating.

[25] See chapter 6, *Evading a Monitoring Network*.

Please Note--The full report is retained in the files of the Committee

Washington Post THURSDAY, SEPTEMBER 6, 1984 A3

Data From Atom Blast Adds To Treaty Verification Questions

By R. Jeffrey Smith
Washington Post Staff Writer

A recent U.S. nuclear testing experiment, aimed at demonstrating a new method of monitoring compliance with a 1974 arms treaty, produced data indicating that the United States may have accidentally breached the treaty, according to U.S. and congressional officials.

The experiment, involving detonation of a U.S. warhead under direct Soviet inspection in the Nevada desert on Aug. 18, was designed to prove that special U.S. sensors—if placed at Soviet test sites—could reliably verify that the explosive force of Soviet nuclear tests is below the Threshold Test Ban Treaty limit of 150 kilotons, equivalent to about 150,000 tons of TNT.

But the sensors, located a few yards from the U.S. warhead, indicated its explosive force was probably between 155 and 163 kilotons, slightly above the treaty limit, the officials said.

Because of associated statistical uncertainties, the results do not necessarily mean that the U.S. blast violated the treaty, they added. A State Department press advisory, prepared in response to inquiries by The Washington Post, said the blast was "in conformity" with the 150-kiloton limit without providing details.

U.S. Ambassador Paul Robinson, reached in Geneva at the continuing U.S.-Soviet nuclear testing negotiations, added that "the test yield was clearly below the [treaty] threshold, and neither we nor the Soviets have a problem with that."

But several officials said the sensor data was nonetheless embarrassing to the administration because it conflicted with a lower yield prediction based on the bomb's design and with a lower estimate based on more traditional seismic sensors located farther from the detonation.

As a result, the Department of Energy (DOE), which conducts U.S. nuclear tests, has reversed an earlier decision not to excavate debris from the underground explosion to determine the warhead's yield with greater precision, several officials said.

"We are conducting additional measurements such as radio-chemical analysis to confirm the yield of the test," the State Department advisory said. "But the results will remain confidential, since we do not discuss the yields of nuclear tests."

Gregory van der Vink, director of a recent study by the congressional Office of Technology Assessment (OTA) on nuclear monitoring, said the results "could be seen as highly awkward" if the new U.S. sensors indicated the blast exceeded the treaty limit, while seismic sensors—often criticized by the administration as unreliable—indicated the blast had been smaller and closer to DOE expectations.

"This provides a clear illustration of how no method of yield estimation is exempt from uncertainty, and an instructive example that people should reflect on when looking at the compliance issue," he said.

Following a review of classified government documents, the OTA report said it found no evidence to support the administration's assertion that 10 out of more than 200 Soviet explosions "likely" violated the treaty limit. "These 10 tests could actually be at or below the 150 [kiloton] limit, but have higher yield estimates due to random fluctuations in the seismic signals," the report said.

Rep. Edward J. Markey (D-Mass.), a nuclear testing opponent, said, "It's delightful to see the same people who misused the seismic data to charge the Soviets with cheating have finally been hoist on their own petard."

A U.S. official, who asked not to be identified, said one of the new sensors, deployed directly over the warhead 2,020 feet below the Nevada desert, indicated the yield was 163 kilotons. Another new sensor, buried in a deep hole 12 yards away, indicated the yield was 155 kilotons.

Another U.S. official said Soviet estimates of the blast's yield, taken from equipment they installed in Nevada under the accord and provided to U.S. officials in Geneva last week, were roughly 10 percent higher than American estimates.

The bomb's expected yield—an estimate supported by readings from distant seismic sensors—was roughly 145 kilotons, the official said. The warhead, which independent experts said was probably drawn from stockpiles for air-launched cruise missiles or land-based Minuteman III ballistic missiles, was selected to "approach," but not exceed, the treaty limit.

The new sensors, which operate by monitoring the rate at which the blast's shock wave crushes a buried electronic cable, produce yield estimates accurate within roughly 30 percent "or better," according to the government's advisory. The OTA has estimated that distant seismic sensors can be just as accurate once test site geology is "calibrated" by the electronic cables.

Troy Wade, acting assistant secretary of energy for defense programs, declined yesterday to discuss the yield estimates, which have been shared with the Soviet Union. But he confirmed that the DOE has shifted its position and now intends to excavate radioactive debris from the test site for "an assessment of the [bomb's] performance."

He denied that the reason was to determine the bomb's yield more precisely, although the assessment will allow such a determination.

Final preparations are under way for a U.S.-monitored Soviet nuclear test near Semipalatinsk, in south-central Russia, on Sept. 13.

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October 19, 1988

The Honorable Claiborne Pell
Chairman
Committee on Foreign Relations
Dirksen Senate Office Bldg. SD-446
Washington, DC 20510

Dear Mr. Chairman,

I understand that on October 6, 1988 the Committee on Foreign Relations held Test Ban Issues hearings concerning monitoring and verification capabilities which might be required for a nuclear test ban treaty. I am enclosing some information that has an important bearing on the seismic verification issue, and which you may wish to include in the record of the hearing.

As you are aware, differences of opinion concerning monitoring capability exist largely because we have to extrapolate the performance of hypothetical seismic networks to areas where we have little data and experience. Consequently these differences will continue to exist until data and experience are obtained directly from within the Soviet Union. Such an opportunity is now about to occur.

Five high-performance seismograph stations have been recently installed within the USSR and are providing scientific data to both U.S. and Soviet seismologists. This remarkable circumstance is the result of a new initiative by IRIS, a consortium of 58 U.S. universities, which has entered into a cooperative program with the Soviet Academy of Sciences. In addition, plans to install another 15 stations within the Soviet Union are being discussed. A copy of the Protocol describing the program is attached herewith.

This initiative presents an unusual new opportunity to resolve some of the remaining difficult technical issues concerning seismic verification of a test ban treaty. Never before has it been possible to obtain such information from within the Soviet Union. The new data will provide direct answers to questions which could not be previously addressed from outside the U.S.S.R..

Yours truly,

Stewart W. Smith
President

cc: IRIS Executive Committee

T H E P R O T O C O L

on scientific cooperation and data exchange in the field of study of Earth structure and earthquake processes, between the USSR Academy of Sciences and Incorporated Research Institutions for Seismology.

The USSR Academy of Sciences(ACADEMY) on one part and Incorporated Research Institutions for Seismology (IRIS) on the other part, recognizing the important scientific and practical significance of international cooperation in the field of seismology,

Taking into account the mutual benefit in exchanging broad-band digital seismological data for solving various seismological tasks,

Taking into consideration the geographical position of the Soviet Union on the Euroasian continent and the significant extent of its territory,

Using the IRIS opportunity to provide high quality digital seismic stations, Academy of Sciences of the USSR and Incorporated Research Inst. for Seismology propose to cooperate in seismological studies under the following terms:

ARTICLE 1

Both sides propose to cooperate in the field of the study of large scale deep Earth structures, as well as in the field of study of strong earthquake sources and geodynamics applying the methods of broad-band seismology and for this purpose to put into operation broad-band digital seismic stations in the USSR territory.

ARTICLE 2

IRIS will supply to the ACADEMY in 1988 five broad-band digital seismological stations. The equipment will be installed by Soviet specialists together with the representatives from the US side.

The location of the stations will be determined by mutual agreement after the possible locations are studied and will be specified in Appendix 1.

ARTICLE 3

The Soviet side ensures operation and maintenance of the stations. In case the equipment is out of order, IRIS will send its experts to provide the necessary repairs or replace the parts that are out of order on request from ACADEMY.

ARTICLE 4

The data recorded by all IRIS stations installed in the USSR will be sent to the IRIS Data Center, on a timely basis as specified in Appendix 2.

ARTICLE 5

The data recorded by the IRIS stations deployed in the USSR, will be accumulated at the same time at the Institute of Physics of the Earth of the ACADEMY . IRIS will provide to the IPE USSR Academy of Sciences the required equipment for reading and transcribing the digital seismic data. Details are specified in Appendix 3.

ARTICLE 6

The data from the stations in the Soviet Union will be available together with data from other global stations, to the international community of scientists on an unrestricted basis.

Data from stations in the Global Network will be available to THE ACADEMY through the World Data Center A for Seismology and also through the IRIS Data Management Center through regular delivery to the Data Center of Institute of Physics of the Earth.

ARTICLE 7

To ensure the above stated works and scientific analysis of the data acquired with the help of IRIS net, both sides agree to implement the exchange of scientists and specialists of up to 6 man-months a year. The host side will cover all the living expenses and the sending side will cover the travel expenses to the other country and back.

ARTICLE 8

The works forseen in the present Protocol will be coordinated on the USSR Academy of Sciences part by the Institute of Physics of the Earth.

ARTICLE 9

The present Protocol has been concluded for a five-year period, subject to availability of funds, and would be extended automatically for a further five-year term, if one of the parties does not notify the other side of its wish to stop its validity within a 6 months period before the term expires.

ARTICLE 10

IRIS and THE ACADEMY view this project as the first step in a more extensive program of instrumentation installation and upgrades and future cooperation which may include additional seismographic facilities in the Soviet Union.

To this end, THE PARTIES may propose additional steps for mutual cooperation in this program.

ARTICLE 11

IRIS and THE ACADEMY anticipate that the arrangements in this protocol and future activities under it would form a project under the Area IX of the US-USSR Joint Committee on Cooperation in the Field of Environmental Protection and in the pending bilateral Agreement on Cooperation in Basic Sciences.

President IRIS

Stuart A. Smith

S.Smith

April 7, 1988

Vice-President
The USSR Academy of Sciences

E.P.Velikhov

07.04.88

Appendix 1

The initial station locations will be Obninsk, Arti, Ircutsk, Kislovodsk, and Garm. During the first year the suitability of conditions at these locations for long-term Seismic Stations will be determined. After the experiment, these locations will be evaluated and equipment may be moved to other locations if necessary.

The schedule for deployment will be August-September 1988. Plans of the stations will be provided to IRIS by IPE by and of April 1988.

The initial station equipment will consist of:

3 component VBB Strekheisen Seismometer covering frequency band .003 Hz to 5 Hz.
16 bit Analog-to-digital converter, high and low-gain channels
Magnetic tape recording system
Serial data line for modem
1 channel visual recorder
Omega clock
Video Terminal
Power System
Data Acquisition and rrecording software.

APPENDIX 2 Data transmission

Data will be recorded on 1600 BPI magnetic tape producing 2 tapes per week for each station. These 2 tapes will be delivered to Obninsk weekly with a normal delay of one week.

After copying the tapes the originals will be delivered to Moscow WDC-B within 1 week.

WDC-B will deliver tapes to an international air carrier for shipment to San Diego within one week. Using thise prosess and under normal circumstances, the tapes would thus reach the U.S. within approximately 30 days of the time the data was recorded. IRIS will pay cost of air shipping to U.S., ACADEMY will ensure a routine process for clearing customs.

Appendix 3 Equipment for Data Center in USSR

In order to provide IPE the capability to transcribe magnetic tapes and to determine that stations are operating correctly IRIS will endeavor to provide a PDP 11/84 system or its equivalent, 3 C-D readers and on initial supply of 200 magnetic tapes.

To facilitate data exchange IRIS will provide World Data Center-B 2 for Solid Earth Geophysics a PC -XT type computer with C-D reader.

All of the equipment to be provided is subject to compliance with U.S. export restrictions.

Prepared Statement for the Senate Foreign Relations Committee
of

Milo D. Nordyke

Senior Scientist
Lawrence Livermore National Laboratory, Livermore, Calif.

October 6, 1988

Thank you, Mr. Chairman, for the opportunity to present my views on the current situation with the TTBT. I will briefly give a few observations on the recently concluded Joint Verification Experiment (JVE) and what it suggests about possible future directions. I should like to make it clear that I am speaking as an individual and not as an official representative of the Lawrence Livermore Laboratory.

As earlier testimony has made clear, the U.S. and the U.S.S.R. have been engaged over the last several years in a series of discussions and, more recently, negotiations regarding ways to improve the verification aspects of the TTBT and PNET. The latest event has been the carrying out of a special nuclear explosion at each country's nuclear weapons test site with the other country participating by making yield measurements similar to those that have been proposed by each side under a TTBT enhancement regime. These two operations have been given the name the Joint Verification Experiment (JVE). The primary objective of the JVE has been to demonstrate the techniques proposed by each side.

In my opinion, the JVE has been extraordinarily useful from a number of viewpoints.

First, it provided a unique opportunity for gaining insights into the logistical requirements such on-site measurements under a treaty monitoring regime would entail. We obtained the first practical experience with the costs of such operations in terms of both the dollars and the manpower and equipment resources required. Further, we gained some practical understanding of the interactions that will occur between such verification measurements and the program of nuclear weapons diagnostic measurements that, under normal circumstances, would have been part of such a field test.

The JVE also provided an opportunity for the scientists of the two sides to interact at a technical level in a field situation where many of the artificialities and constraints imposed by the negotiating environment were much less prevalent. For the first time both sides were able to learn in some detail how the other side carried out this common enterprise called nuclear

weapons testing. We also learned about a number of sensitivities that will be good lessons for future negotiations.

The JVE also demonstrated that results are not always predictable when dealing with experimental measurements. The JVE underscored the fact that we must be prepared to deal with such results in a statistical framework - something that the U.S. has found hard to do in the past.

Second, the JVEs have demonstrated the Soviet willingness to accept verification measures that heretofore would have been regarded as unprecedented intrusions into their nuclear weapons testing program. Over 100 Americans have traveled to the Soviet Test Site with a comparable number coming to our Nevada Test Site (NTS). Much of the information called for in the 1974 TTBT Protocol has now been exchanged for the two country's high-yield testing areas. This was something the Soviet Union had long refused to do before ratification of the treaty.

Third, the JVEs have provided data relevant to the issue of Soviet compliance with the 150 limit of the TTBT. Even though the hydrodynamic yield and seismic measurements constitute only one data point and must be used with caution, the range of opinion about the geophysical parameters involved in the estimation of yields at the Soviet test site has been so wide that even one data point is useful. Specifically, the key issue from a compliance point of view has been the existence or non-existence of a factor called the magnitude bias for explosions at the Soviet test site relative to explosions at NTS. There are a variety of geophysical and seismological studies that indicate that the seismic magnitudes from explosions at the NTS are systematically reduced by a factor of between 1.5 and 3 in terms of yield relative to the magnitudes for the same yield explosions at Semipalatinsk. However there are a number of people who simply don't believe that this factor exists and that it represented a concession to the the Soviet Union They argue that we should use the same relationship between magnitude and yield for both test sites. This range of opinion within the policy community has made it difficult to reach a consensus regarding the TTBT compliance issue.

We now have measured the yield of a nuclear explosion at the Shagan River Test Site near Semipalatinsk with an on-site technique that is believed to be significantly more accurate than the current seismic yield methodology and to have no bias of its own - the hydrodynamic technique defined in the PNET using the CORRTEX instrumentation. We also have measurements of the seismic magnitude for this explosion. The U.S.G.S. National Earthquake Information Service (NEIS) measured a seismic magnitude of 6.1 for the Soviet JVE explosion. If that explosion had been fired at our Nevada Test Site, such a magnitude would correspond to a yield of at least 350 kt or even larger if it had been fired in one of the lower coupling geologic media available there. I can't tell you the yield measured by the CORRTEX equipment at Shagan, but I

can assure you that if it had been anywhere close to 350 kt you would have read about it in the New York Times or Washington Post by the time.

So I think that it is fair to say that this one explosion has established that there is a bias factor that must be applied before we can use NTS data to estimate the seismic yields at the Soviet test site and we are now only arguing about the value to be used for the bias. One explosion is clearly not enough to do that with any certainty, but a fairly rudimentary statistical analysis shows that, taking into account what we already know about the credible range of values for the bias, it can be reasonably well determined for a given testing area at Semipalatinsk with 3 or 4 calibration explosions. Such a determination of the bias would reduce the overall error associated with the seismic yields to be significantly less than the oft-quoted value of 2. If multiple seismic signals from each explosion were used for seismic yield estimates instead to the one signal currently used, I believe that the overall error after 3 or 4 calibration events would be somewhere in the 30-40% range for explosions greater than 50 kt.

I'd now like to turn to what the JVE can mean for the future. As has been outlined here earlier by others, the U.S. Government is proposing an enhanced verification regime for the TTBT that would include the deployment of a hydrodynamic yield measurement on all future nuclear weapons tests carried out by the two sides which had an intended yield greater than some value. At the present testing rates, this would probably mean something like 4 to 6 deployments per year by each country to the other country's test site. These deployments would be on nuclear weapons tests, not on simple explosions carried out for demonstration or yield calibration purposes such as the JVE. While the hydrodynamic measurements would be similar, the operational aspects growing out of the required geometrical restrictions will make many of them significantly more complex.

As I testified to this Committee and to the Senate Armed Services Committee last year, I believe that enhanced verification of the 1974 TTBT is needed before it should be ratified. However, we should be cautious in our approach. It used to be that we knew the Soviet Union would reject almost all of our verification proposals at an early stage and argue for the minimum credible verification regime and so we generally believed that anything the Soviet Union accepted would be acceptable to us. Today however, as the INF Treaty clearly shows, its a different world in the Soviet Union when it comes to treaty verification. Today she appears willing to accept almost any verification proposal made by the U.S. and then throw in a few ideas of her own. In that kind of world, we must be much more careful than in the past to be sure that any verification regime we ask for will contribute to the long term stability of our relationship as well as not work against own vital interests.

With any verification regime, there are costs and benefits which must be balanced. For the TTBT, the costs can be measured in terms of the dollars and resources required, the interference with and diversion of our on-going research and development programs, and the possibilities of providing classified information to the other country on our nuclear design program. The JVE demonstrated that the costs associated with such measurements will be substantial. The operational interference and geometrical restrictions that must be imposed may well impact the design of some of our tests such as nuclear directed energy weapons tests which have unique geometric arrangements. Inspection of the canisters of these tests to verify that treaty restrictions were being followed could well reveal sensitive design information although measures would be taken to minimize such risks. The inherent openness of our society makes it much more difficult for us to limit the intelligence opportunities offered by the constant presence at each other's test sites that is inherent in the administration proposals.

The benefits can be measured in terms of greater assurance regarding compliance, enhanced deterrence of evasion of the threshold limitation and the opportunities for gaining information about the other country's mode of operation and decision-making processes.

I continue to believe as I did a year and a half ago, and the JVE has reinforced this belief, that the best balance of the costs and benefits involved in an enhanced verification regime for the TTBT will be found in a program involving a specified number of calibration events - not necessarily nuclear weapons tests - whose yields are verified by on-site hydrodynamic yield measurements. Combination of the data from these calibrated explosions with a seismic yield methodology that utilizes all the seismic data available can give seismic yield estimates that will have an accuracy close to that obtainable with on-site hydrodynamic measurements for tests above 50 kt. Such a regime would provide yield estimates for Soviet explosions with significantly higher confidence and smaller errors than at present while limiting the costs and other negative impacts on our nuclear weapons program.

TESTIMONY OF

DR. DAVID W. HAFEMEISTER

PROFESSOR OF PHYSICS

CALIFORNIA POLYTECHNIC STATE UNIVERSITY

ON THE

VERIFICATION AND COMPLIANCE

OF NUCLEAR TESTING TREATIES

BEFORE THE

COMMITTEE ON FOREIGN RELATIONS

OF THE

UNITED STATES SENATE

OCTOBER 6, 1988

Mr. Chairman,

PURPOSE OF THE TESTIMONY

Thank you very much for the opportunity to testify on the verification and compliance of the Threshold Test Ban Treaty (TTBT). My remarks today will focus on (1) the compliance decision, and (2) the compliance-judgement process. From January to December 1987, I was the technical lead for the State Department on the TTBT Interagency Work Program. I have since returned to my permanent position as Professor of Physics at the California State Polytechnic University; this testimony is written in my individual capacity. Policy decisions always involve difficult tradeoffs between dissimilar objects, which is why we have elections to pick leaders with visions of the future. On the other hand, a compliance decision is judicial in nature and it involves different issues. As in the courts, we have to ask:

(1) What did the law or the treaty say?
(2) What is the evidence?
(3) Is the same standard of evidence applied to both sides in a consistent manner?
(4) Who decides that evidence is inadmissible, and that standards are consistent?
(5) Does the treaty partner have an advocate, or at least a position paper, which will present his side, no matter how unpopular?

In my testimony, I will indicate that the compliance process in the Executive Branch has not always been a judicial process since the third, fourth and fifth criteria have been violated. When one examines the Soviet noncompliance charges against the U.S., the same questions can be asked of the Soviet process for determining compliance charges. My intent today, is not to belabor the errors of the past, but rather -- how can we do better in the future. It is my belief that the process for compliance decisions must be treated differently than the normal process for policy decisions. If arms control is to have a future, we must develop more judicial, internal procedures to enhance the fairness of the compliance process. In my testimony I will offer some suggestions to improve the compliance process that could be considered by the next Administration (which has the responsibility to carry out the compliance process), the next Congress, and by the Soviet Union.

I. COMPLIANCE WITH THE TTBT

SUMMARY STATEMENT ON COMPLIANCE: I would like to underscore the important conclusion of the recent Office of Technology Assessment (OTA) report, Seismic Verification of Nuclear Testing Treaties. While at the State Department, I examined the relevant data from all the interagency working groups, involving both seismic and other data. In particular, I carried out a thorough statistical analysis of the seismic data, taking into account the random and systematic errors and using the accepted U.S. government value for the bias factor. I agree with the Defense Intelligence Agency (DIA) report of 1985 (which is cited in the OTA report) and other internal studies that the seismic data sets are the most meaningful for the present consideration of the past Soviet compliance with the TTBT. In the future, when the calibrations of the test sites are completed, the systematic errors in the seismic data will be reduced, and at that time the data should be reexamined. Since all the measured yields of the largest Soviet tests fall within statistical uncertainties of the measurements centered at 150 kt, it appears that the Soviets are complying with the limit of 150 kilotons. If one applies the same standard of evidence to the testing programs of both the U.S. and the U.S.S.R., one can state that both

sides are complying to the TTBT within the accuracy of the measurements. Because of the statistical uncertainties, one can not rule out that a very few Soviet or American tests may have exceeded the 150 kt level by only a small amount, but when one considers the distribution of tests this does not constitute a violation. Thus, it is incorrect to state, as it does in the President's report to the Congress on Soviet noncompliance, that the Soviet nuclear tests are a "likely violation." Furthermore, virtually all of the technical people analyzing these data in the other agencies reached the same conclusions. Therefore, I agree with the OTA report on this issue which states that:

"All of the estimates of Soviet and U.S. tests are within the 90 percent confidence level that one would expect if the yields were 150 kt or less. Extensive statistical studies have examined the distribution of estimated yields of explosions at Soviet test sites. These studies have concluded that the Soviets are observing a yield limit consistent with compliance with the 150 kt limit of the Threshold Test Ban Treaty." (page 17)

MORE DETAILS: Because of the classified nature of the data, there will be a lack of numerical specificity in my testimony. In this particular compliance case, this is unfortunate because there is no military significance in the slightly more accurate, classified sesimic magnitude values, and the agreed U.S. government value for the bias factor. In other words, this discussion would be enhanced if we could lay the data out on the table and discuss it. There are two main errors that one must consider when analyzing the data, random errors which give a fluctuating value of measurement about a central value, and systematic errors, such as a zero set on a scale. Publicly, the U.S. government has stated that the present seismic technology is within a factor of about two (F=2). This means that 95% of the explosions at exactly 150 kilotons (kt) would measure between 2x150 (2F), or 300 kt, and 150/2 (F/2), or 75 kt. Alternatively, this means that 1 event in 40 would appear above 300 kt if F=2. The OTA report states that all of the Soviet and U.S. tests are within (or below) the F=2 criteria. I agree, and so does everyone else in the "process" that the events are considerably below the 150x2=300 kiloton limit. Thus, if one is to claim noncompliance, one must assert one of the following:

ERRORS IN THE BIAS FACTOR. The relative difference between the seismic signals from the Nevada and Semipalatinsk test sites is call the bias factor. The bias factor has not yet been directly measured by the United States Government. At this time, interagency task forces have examined the indirect determinations of the bias factor, and given their interpretation of the data, which was ultimately accepted by the Executive Branch process[1]. More direct measurements of the bias factor could ultimately come from further Joint Verification Experiments. By ignoring the systematic error in the bias factor, one can make the old (uncalibrated, no L_g data) seismic data appear to be much more accurate than it really is by considerably reducing the apparent F factor. By avoiding the systematic error, one in effect pushes some of the events beyond the upper limit (2F) because F is smaller. Some have incorrectly argued that the error on the bias factor, as adopted by the Executive Branch, is a political decision, and that the political process, by definition, does not make an error in its judgements. But we all know, that both scientific measurements and political decisions have errors, and we must take them into account. To ignore the systematic error in the bias, at this time without calibration, is to make a very large error in one's analysis.

NONSEISMIC DATA ON SOVIET TESTS: If the argument for noncompliance cannot rest on the seismic data (as indicated above), then it must depend on other, nonseismic data. The OTA report references a letter[2] from Dr. Roger Batzel, Director of the Lawrence-Livermore National Laboratory to Senator Pell, Chairman of the Senate Committee on Foreign Relations (February 23, 1987):

"We have considered the non-seismic evidence as well as the seismic evidence. Our conclusion, like that of the DIA panel which also reviewed all the data, is that the seismic evidence is currently the most reliable basis for estimating the yields of Soviet underground nuclear explosions. We continue to attempt to reconcile the available data. However, we believe that the interpretation of the past Soviet test program which is the most consistent with the best available data is that: The Soviets appear to have obeyed a testing limit. The limit is consistent with compliance with the provisions of the TTBT. The uncertainties of the yield estimation process are such that we cannot rule out the possibility that a few of the tests could have exceeded the threshold. These uncertainties are, in part, the source of the differences in the assessments of the extent of Soviet compliance with the TTBT. On-site hydrodynamic yield measurements would help to reduce the uncertainties and improve confidence in the results of the compliance evaluation process."

From what I know about the data, the Livermore and OTA conclusions are correct. I have done independent calculations on the compliance and calibration data. I have participated in the groups that analyzed the non-seismic data. I have spent a considerable amount of time with scientists, at the working level, on all of these technical issues. From my work and these discussions, I find a great unanimity among the scientists on the conclusions on compliance by OTA and LLNL. On the other hand, I take a great exception to the Executive Branch testimony[3] before the House Foreign Affairs Committee on June 28, 1988 that "Furthermore, the totality of evidence strengthens the previous finding of likely TTBT violation." This statement implies that the nonseismic data were good enough to prove the case, which is in disagreement with the DIA and other reports.

REPORT TO CONGRESS ON SOVIET NONCOMLIANCE WITH ARMS CONTROL AGREEMENTS. The most recent report[4] to the Congress on the Soviet noncompliance on the TTBT stated that:

"While, in view of ambiguities in the pattern of Soviet testing and in view of verification uncertainties, the available evidence is ambiguous and we have been unable to reach a definitive conclusion, this evidence indicates, that Soviet nuclear-testing activities for a number of tests constitute a likely violation of legal obligations under the TTBT." (emphasis added)

According to Webster's Dictionary, a "likely" event is one which is "probably destined to happen or be." Thus a likely event must be much more probable than a "not-likely event." The concluding charge of "likely violation" in this sentence does not logically follow from the preamble portions of the sentence. One can only conclude that the Executive Branch must have been split over the issue, and that the National Security Council attempted to patch the disagreement together.

WHY HAS THE EXECUTIVE BRANCH MAINTAINED THE CHARGE OF "LIKELY VIOLATION?" The original charge of noncompliance on the TTBT was released to the Congress on January 23, 1984. According to Duffy[1], "In January 1986, Director of Central Intelligence William Casey reportedly changed the CIA procedures for estimating the yields of large Soviet tests to conform to the recommendations of review panels." In other words, the value of the bias factor was increased, and the case of "noncompliance" was severely weakened. In December 1985 President Reagan signed National Security Decision Directive 202, requesting a review of how the methodological changes would affect the past U.S. charges of Soviet violations." In my view, some members of the Executive Branch felt that they were locked-in to continue the charge of "likely violation" because of the great inertia of history. In 1984, the U.S. made the charge of noncompliance on a number of issues, such as TTBT and the Krasnoyarsk radar. In 1986, the charge of noncompliance with the TTBT was greatly

weakened by the change of the bias factor, but, of course, the Krasnoyarsk radar continues to be a violation, no one disputes that. (The military significance of Krasnoyarsk at this time is essentially nil, but it still is a violation until it is torn down.) Many observers think that the compliance process can be used as a tool to send the Soviets a message that we are, in general, unhappy with their behavior, and that to backtrack on the TTBT compliance issue would be to send the wrong message. There may be some truth in this argument, but the broader question is "should one use any means to obtain one's ends, and will it be counterproductive?" Most of us would be discouraged if the justice system of our country was used to accomplish goals beyond the original allegations. In my testimony I maintain that the "compliance-judgement process" must be held to the same general standards on which our country's judicial system is based. My conclusion is that the "likely violation" charge would not be made now, except for the momentum of the past noncompliance charge.

HOW MUCH VERIFICATION IS ENOUGH? A SENSITIVITY ANALYSIS OF THE THREAT TO NATIONAL SECURITY DUE TO A BREAKOUT FROM THE TTBT: Five years ago, I published[5] a variational calculation on the survivability of U.S. strategic forces if the Soviets improved their weapons in a variety of ways. These calculations were based on the unclassified data sets from the International Institute for Strategic Studies in London. My results showed that the survival of U.S. forces was much less sensitive to increases in the yield parameter than to improvements in the accuracy (CEP) and reliability. Many other authors have obtained similar results. While in the Executive Branch, I carried out similar calculations using the real data on computerized exchange models. These results confirmed the above conclusion that variations in yield were much, much less important than variations in accuracy or reliability. The policy process should examine these kinds of effects when considering verification technologies.

II. THE COMPLIANCE-JUDGEMENT PROCESS

HOW CAN THE INTERAGENCY COMPLIANCE PROCESS BE IMPROVED? A PROPOSAL FOR THE U.S. AND THE SOVIETS. The last part of my testimony is not based on science, but rather, it is intended as a provocative suggestion in order to have us focus on the improvement of the compliance process. In my view the compliance process would be improved if the Executive Branch adopted more judicial procedures for the compliance process. As one examines the Soviet charges of U.S. noncompliance, it rapidly becomes clear that many of their charges can be dismissed without seeing the data. For example, the deployment of Pershing Two missiles was not a violation of SALT, and so forth. Thus, my suggestions (rather than criticisms) are relevant to both sides, and, in my view, one shouldn't belabor the fact of which side was more illogical. Let us admit that we both can improve, and leave it at that. Within this spirit, I offer the following three possible rules of conduct for compliance deliberations in the United States and in the Soviet Union in order to carry out the criteria 3 to 5, listed in the first paragraph of this testimony:

-- The same standard of evidence shall apply when considering (1) U.S. charges of Soviet noncompliance and (2) U.S. compliance with the same treaties. We should encourage the Soviets also to apply the same standards for the two situations that they face.

-- The interagency group as a whole shall rule on the validity of the standards of evidence used, with disagreements directly appealable to the National Security Council.

-- The treaty partner, which is not in attendance to present its views, shall be represented by either an interagency paper representing their views, or preferably by an experienced advocate, appointed by the President or his designate. It is the responsibility of the advocate, or position paper to argue against unreasonable positions and ask hard questions of the other agencies. This process could encourage the Executive Branch to ask their treaty partners additional questions which might, or might not, clairfy the situation. We should encourage the Secretary General to appoint an "American Advocate" to the Soviet internal compliance proceedings.

CAN THESE RULES BE IMPLEMENTED? No matter which party controls the Executive Branch, it is unlikely that the Executive Branch will want to consider formalizing their compliance-judgement process for fear of infringement by the Congress on their national security process. It is very unlikely that the Congress can dictate the details of the classified, national-security process. However, the Congress could require the Executive Branch to study these rules of fairness, consider other improved procedures, and examine the possibility of their implementation. Without some action along these lines some of the problems will continue, such as:

(1) In the past, two different standards have been used, on at least two occasions, which required a higher standard from the Soviets, than from the U.S. A judicial process demands the same standard.

(2) Because the 6 agencies in the compliance process don't wish to be viewed as too favorable toward the Soviets, it becomes somewhat difficult to combat unreasonableness and ask the hard questions.

(3) When there are many issues at the interagency process, defending due process for the Soviets becomes expendable.

Thank you very much, Mr. Chairman, I will gladly answer questions you have.

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